High up in the North in the land called Svithjod, there stands a rock. It is a hundred miles high and a hundred miles wide. Once every thousand years a little bird comes to this rock to sharpen its beak.

When the rock has thus been worn away, then a single day of eternity will have gone by.

(Van Loon, 1951)

THE UNIVERSITY OF ALBERTA

STRUCTURAL STUDIES OF THE GOLD-MINERALIZED SHEAR ZONE AT GIANT MINE, YELLOWKNIFE, NORTHWEST TERRITORIES

by

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A THESIS

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ABSTRACT

In the Yellowknife greenstone belt gold-bearing schistose shear zones cut obliquely across vertical pillowed and massive basic volcanic rocks of the Archean Kam Formation. Data on the orientations of joints, faults, veins, slickenside striae and fibrous mineral growths were collected from within the ASD shear zone of the Giant Mine in a series of straight line traverses on the 950, 1100, 1250 and 1500 levels of the mine near the "C" Shaft. The data were recorded on computer-oriented field sheets. A structural data file was built using DISCODAT, a computer-based system that allows data to be stored, retrieved and manipulated. Equal-area orientation diagrams were produced by the computer for all structural types for each of the levels and for certain subdivisions across the shear zone. The Terzaghi weighting factor, which is based on the angle between a structure and the line of traverse, was used in the preparation of these diagrams.

A nearly vertical joint set with a dip-direction of N305° parallels schistosity within the ASD zone. Other common joint sets have orientations of N210/87° and N100/60-90°. An approximately horizontal joint set is found locally. Two predominant groups of vertical faults have dip-directions of N270° and N335°. This conjugate set is bisected by the shear zone schistosity. The three major sets of veins have orientations of N90/85°, N185/85° and N240/75°. Eighty-seven percent of the lineations observed on fault and joint surfaces are fibrous growths, mainly of carbonate. The remainder are nearly all slickenside striae. All diagrams of lineations show a north-south girdle of points about a horizontal east-west axis. The orientations of the four most prominent

clusters of points are N10-10°, N20-75°, N180-70°, N185-20°. Less common lineations plunge gently NE and SW. These lineations are traces representing the orthographic projection of a single line, which has an orientation N93-3°. This is the regional kinematic direction - thought to be one of extension owing to the predominance of fibrous slickensides.

Assuming that deformation within the shear zone approximates to simple shear and that schistosity originated at 45° to the direction of shear, it was concluded that the minimum shear strain and displacement across the ASD zone are 2.5γ and 380 m, respectively, and that the X:Z strain ratio is about 8:1. Thin sections reveal that there was much microfaulting parallel to the foliation and that the simple shear model might not hold up to more rigorous analysis. However, similar figures for shear strains were derived from published orientation data for the Con (3.7γ) and Campbell (5.5γ) shears.

During regional metamorphism ductile deformation saw the development of the shear zones. Regional flattening then caused the Giant shear zone system to be folded and formed the antiform-synform pair. Later brittle deformation included faulting and jointing. Finally, fibrous mineral growth accompanied a regional east-west extension.

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Chapter I

INTRODUCTION

Yellowknife is situated on the north side of Great Slave Lake in the Northwest Territories. The lake forms the southern boundaries of the Slave Structural Province, the rocks of which include extensive plutonic complexes and volcanic and sedimentary sequences. The basalts and andesites of the Yellowknife greenstone belt have been tilted on edge, and they have the north-south trend typical of the southern part of the Slave Province. The gold ore-bodies of the Giant Yellowknife Mine occur in schistose shear zones that strike subparallel to the greenstones. The gold is associated with quartz bodies localized by dilatancy within the shear zones.

This thesis sets out to elucidate the structural geology of part of the Giant Mine with the help of computer processing. It also relates micro-structures to mesoscopic aspects of the geology, and applies these observations to the general structure of the Yellowknife area. Finally, simple strain analysis provides some data on the amount of deformation the rocks at Yellowknife have undergone.

Structural data were collected from four levels of the Giant Mine near its 'C' Shaft. Observations were made along 4500 feet (1400 m) of drift and cross-cut walls in a series of straight line traverses, up to 100 ft. long. Information was recorded on three types of specially designed, computer-oriented field-sheets. "Traverse line sheets" were used to record general information pertinent to each traverse. Non-penetrative planar structures such as joints, faults and veins were described on "discontinuity data sheets" according to type, orientation,

size, etc. These sheets were also used to record the orientation of various linear structures. The third field sheet, the "lithology data sheet", was used to describe rock types and penetrative planar structures.

The first step in processing the data involved the creation of a data file. The information on the field sheets was punched onto computer cards and subsequently transferred to tape. A general search and retrieval program made it possible either to save permanently subsets of data, or to retrieve the data records and place them in a separate file. Files of line numbers ("keys") referenced data subsets and made it unnecessary for the computer to scan the entire data file. Mathematical manipulation of the data was based on the use of direction cosines of unit vectors. A series of density diagrams of linears, poles to joints, etc., was generated using the computer. Inherent in the computer programs were corrections for the effects of non-random orientation of the traverse lines.

Initial structural analysis was based on comparisons of stereograms for the 14 major keys. The second step involved comparing stereograms developed for combinations of these keys. Each structural type (joints, faults, veins, etc.) was investigated by level and by longitude (representing the various levels of the mine under study, and an arbitrary division at certain mine grid eastings), and then by level and longitude combined.

Thin sections were investigated for micro-structures and veins. They were made from oriented samples collected from the study area, and from a diamond drill core drilled across the main Giant shear zone. A

number of thin sections were stained to distinguish between carbonate minerals.

The analysis of strain across the ASD zone was based on a technique developed by Ramsay and Graham (1970) in which they used the orientation of the schistosity within a shear zone relative to the shear zone to investigate the change in strain across the zone. Having made certain assumptions, it was possible to derive figures for the strain across the ASD zone, the minimum displacement along it, and the strain ratio. Cruden's (1971) method of determining the regional kinematic direction from the orientation of lineations on faults and joints was used and modified slightly to get an estimate of a late extension direction.

Chapter II

GEOLOGY OF THE YELLOWKNIFE AREA

A. GEOLOGIC SETTING

The Slave Structural Province (fig. 1) underlies an area of about 190,000 sq km in the northwestern Canadian Shield between Great Slave Lake and Coronation Gulf. It is bordered on the west by the Bear Province, and on the east and southeast by the Churchill Province. To the southwest is the Paleozoic cover of the Interior Platform and to the north are the flat-lying Paleozoic rocks of the Arctic Islands. The Slave Province has remained comparatively stable for the last 2500 million years (McGlynn and Henderson, 1972). The rocks include highly deformed and variably metamorphosed Archean volcanic and sedimentary sequences separated by extensive plutonic complexes (McGlynn and Fraser, 1972). The non-plutonic sequences are generally simple, comprising thick assemblages of greywacke-mudstone sediments that overlie subaqueously extruded mafic volcanic rocks. Their structure is complicated. Whereas the more competent volcanic sequences commonly occur as steeply dipping homoclinal successions, an intricate pattern of refolding characterizes the sediments (McGlynn and Henderson, 1972; Fyson, 1975). The sedimentary and volcanic sequences outline three north-trending zones (McGlynn and Henderson, 1970), one of which extends into the south-central part of the Slave Province and underlies the area east of Yellowknife. Radiometric dates with a mean of 2480 m y suggest that deformation, metamorphism and plutonism occurred during the Kenoran Orogeny.

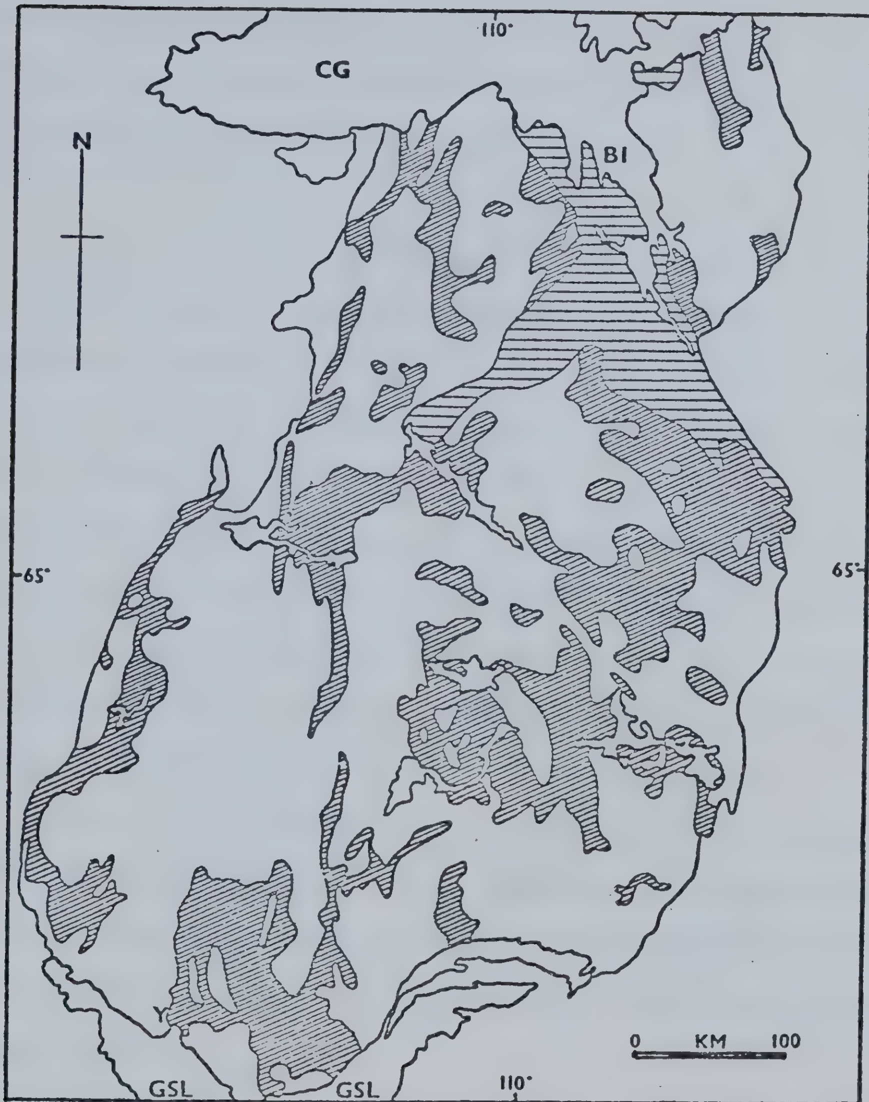

Fig. 1. Simplified geology of the Slave Province. Horizontal lines: Aphebian cover; oblique lines: Yellowknife Supergroup supracrustals; clear: granitic rocks; BI: Bathurst Inlet; CG: Coronation Gulf; GSL: Great Slave Lake; Y: Yellowknife. Modifed from McGlynn and Henderson (1972).

In the Yellowknife area the greenstones, dated at about 2650 m y (Green, 1968; Green and Baadsgaard, 1971), are somewhat older than the granitic plutons - the Western and Southeastern Granodiorites and the Prosperous Lake Granite. A faulted synformal structure appears to run approximately north-south beneath Yellowknife Bay.

B. STRATIGRAPHY

The 'Yellowknife Supergroup' (Henderson, 1970) includes the diverse assemblages of Archean sedimentary and volcanic rocks within the Slave Province. In the Yellowknife area Henderson (1970) divided the 16 km pile of volcanic and sedimentary rocks that locally comprise the Yellowknife Supergroup into two groups and six formations (see fig. 2). The predominantly volcanic Beaulieu Group consists of the Kam and Duck Formations. The volcanic Banting Formation has not been assigned to a group. The largely sedimentary Duncan Lake Group contains the Jackson Lake, Burwash and Walsh Formations (Hoffman and Henderson, 1972).

The west side of Yellowknife Bay is underlain mainly by the Kam and unconformably overlying Jackson Lake Formations. To the east the oldest rocks exposed belong to the Duck and conformably overlying Burwash and Banting Formations; locally the Walsh Formation rests directly on the Burwash Formation.

1. The Kam Formation

The Kam Formation comprises the northerly-trending 'Yellowknife Greenstone Belt', consisting of about 9 km of mainly basaltic and andesitic volcanic rocks. Massive and pillowed flows, 1-150 m thick, crop out in roughly equal amounts. Lenses and sills of dacitic material,

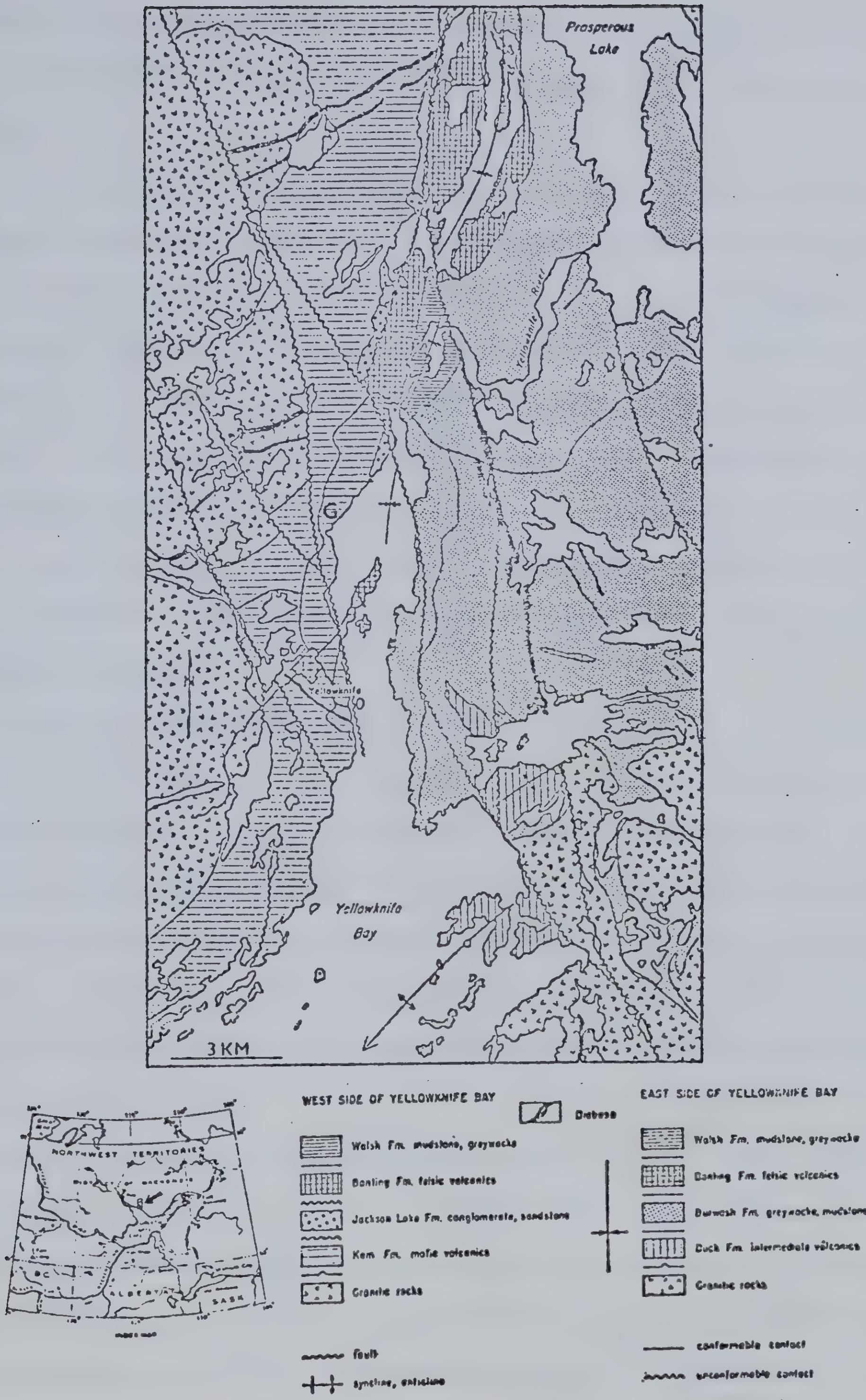

Fig. 2. Generalized geology of the Yellowknife area. Modified from Hoffman and Henderson (1972). G: Giant Mine.

dykes of diabase and gabbroic rock, and agglomerates, breccias and tuffs of various types complete the succession (Henderson and Brown, 1952, 1966).

The massive flows are relatively coarse and for the most part lack internal structures. Consequently, the coarser flows and intrusive sills are very difficult to tell apart if the contacts are hidden (Henderson and Brown, 1952, 1966). The internal structure of the pillowed flows is everywhere well developed and from place to place the contacts are marked by layers of flow breccia, fragmental breccia or tuff. Although a few flows have a pillowed upper part and a massive, coarser-grained lower part, most are either pillowed or massive throughout. Commonly, tuffs rest directly on pillowed flows and infill the interstices between the uppermost pillows.

Certain of the pillows are variolitic. The spherules, up to 10 mm across, are most distinct on weathered surfaces, where they are greener in colour and more resistant to erosion. Henderson and Brown (1952, 1966) reported them as being composed of a very fine-grained mixture of epidote, hornblende and oligoclase, and rather richer in feldspar than the rock as a whole. The few flows that contain spherules are useful markers in the somewhat monotonous greenstone assemblage and they can be traced for long distances along strike.

Rare phenocrysts, up to 20 mm across, occur in a few basalt and andesite lavas towards the top of the sequence. The Townsite flows, which lie northwest of Yellowknife townsite, comprise a 400 m thick assemblage of porphyritic quartz-feldspar meta-dacite flows, and associated agglomerates, breccias and tuffs. A large meta-gabbro sill divides the flows into two units.

Pyroclastic rocks occur throughout the volcanic sequence but are more abundant in the upper parts. Agglomerates and breccias occur in irregular bands whose average thickness is about 2-3 m, but which locally attain thicknesses of several hundred meters. The bands are continuous and maintain a constant orientation. Most are composed of fragments up to 0.5 m across which have the composition of the enclosing lavas. Tuffs occur in continuous bands 50 mm to more than 35 m thick, that can be traced along strike for several kilometers. Coarse, feldspar crystal tuffs are found together with fine, well bedded, cherty types.

2. The Jackson Lake Formation

The Jackson Lake Formation lies with small angular unconformity on the Kam Formation. A basal conglomerate, of mainly local mafic volcanic derivation, is overlain by fine-grained, silicic, volcanic, lithic wackes, minor mudstones, and scattered conglomerate horizons. The formation is faulted against the overlying Banting Formation so the top is nowhere exposed. A maximum thickness of 240 m is reached (Henderson, 1970).

3. The Duck Formation

The Duck Formation consists of intermediate volcanic rocks. Although they are less basic and contain more associated glassy material than the Kam volcanics, pillowed flows are common, and Henderson (1970) considered them to be the eastward lateral extension of the Kam Formation. The base of the Duck Formation is not exposed.

4. The Burwash Formation

Estimated to be about 4600 m thick (Hoffman and Henderson, 1972), the Burwash Formation consists of interbedded greywackes and slates conformably overlying the Duck Formation and underlying the Banting Forma-

tion. Henderson (1970) noted that the Burwash Formation 'grades into' the Walsh Formation.

5. The Banting Formation

The Banting Formation is volcanic in origin and variable in composition, with porphyritic dacite flows, felsic volcanics, pillowed andesites and crystal tuffs. Henderson (1970) postulated that it represents an eastward extension of silicic volcanic units that once capped the Kam Formation. The formation thins southeastwards from about 1300 to about 800 m. A fault or a major shear zone separates it from the underlying Jackson Lake rocks (Henderson, 1970). Relationships with the underlying Burwash and overlying Walsh Formations are obscure but the formations appear to be conformable.

6. The Walsh Formation

Along the shores of Walsh Lake, the shales, siltstones and greywackes of the Walsh Formation lie stratigraphically above the Banting Formation. Although the contact between the Walsh and Burwash Formations is obscured by Pleistocene sand, Henderson (1970) suggested it is gradational. Owing to its deformed nature and the absence of an upper contact, Henderson gave no estimate of the thickness of the formation.

C. IGNEOUS ROCKS

In the Yellowknife area the Yellowknife Supergroup has been intruded by three major granitic plutons and several lesser igneous bodies.

1. The Southeastern Granodiorite

A foliated biotite granodiorite grading to quartz diorite around its western flanks, the Southeastern Granodiorite was emplaced at the begin-

ning of the Kenoran Orogeny, 2620-2640 m y ago (Green, 1968; Green and Baadsgaard, 1971). It has a narrow metamorphic aureole (Jolliffe, 1942), a lobate outline and contacts suggesting diapiric emplacement (Ramsay, 1973). Green (1968) noted that the western section contains many metavolcanic xenoliths, but pointed out that boulders of the pluton form a substantial part of the conglomerate horizon in the Sub Islands. He warned that if the Sub Islands outcrops are stratigraphically equivalent to those at the north end of Yellowknife Bay, the Southeastern Granodiorite must predate at least part of the Yellowknife Supergroup.

2. The Western Granodiorite

The Western Granodiorite is a massive, homogeneous and mostly unfoliated, discordant pluton of quartz diorite to quartz monzonite composition (Green, 1968; Ramsay, 1973). Aplite dykes up to 7 m thick are relatively common near contacts with the Yellowknife Supergroup. The metamorphic aureole of the pluton extends approximately to the west shore of Yellowknife Bay. According to Green and Baadsgaard (1971) it was emplaced around 2595-2610 m y ago.

To the south, the contacts with the Yellowknife Supergroup are sharp, but northwards they become more diffuse (Green, 1968). The contact zone varies in width from a meter or so to about 1 km wide. It is marked by many included blocks of greenstone, some of which are 90 m across. Locally the blocks are angular, but elsewhere they have diffuse margins and evidence of assimilation is widespread (Green, 1968).

3. The Prosperous Lake Granite

The youngest major pluton in the area (2572 m y - Green and Baadsgaard, 1971), the Prosperous Lake Granite is a fine to medium-grained

biotite-muscovite quartz monzonite (Ramsay, 1973). Quartz-microcline-albite-muscovite-tourmaline-garnet pegmatites form almost half of the body, tending to be concentrated near the margins (Green, 1968). Country rocks are meta-sediments of the Yellowknife Supergroup against which the Prosperous Lake Granite has cross-cutting relations and sharp, intrusive contacts (Ramsay, 1973). The broad metamorphic aureole approximates an Abukuma facies series, and the pluton and its aureole are typical of late potassic granites that crop out throughout the Slave Province (Ramsay, 1973).

4. Contaminated (hybrid) Rocks

In several localities, e.g., west of Ryan Lake, there is evidence for contamination of the granodiorite with greenstones (Green, 1968). Green (1968) traced the progress of the reaction, noting the conversion of basic plagioclase (An_{55}) to oligoclase (An_{25}). (For a detailed description, see Green, 1968, pp. 36-38.)

5. The Stock Lake Stock

The Stock Lake Stock is an ovoid body, about 1500 m by 600 m in size, thought to be an apophysis of the Western Granodiorite. There is little noticeable contact alteration as the stock intrudes the greenstones in the aureole of the Western Granodiorite in the almandine-amphibolite facies (Green, 1968).

D. METAMORPHISM

All sedimentary and volcanic rocks within the Slave Province are metamorphosed to at least lower greenschist facies, and many belong to higher grades (Ramsay, 1973). High-grade metamorphic aureoles occur

around plutons, with late potassic granites being surrounded by broad zones of porphyroblastic rocks.

Little is known of the metamorphic zonation around such syntectonic plutons as the Western and Southeastern Granodiorites at Yellowknife. According to Folinsbee (1942) meta-sediments are characterized by a chlorite-biotite-andalusite-staurolite-garnet zonal sequence in the aureoles. In the volcanic rocks adjacent to the Western Granodiorite, Boyle (1961) mapped greenschist facies rocks in a small area east of Bow Lake, epidote-amphibolite facies throughout most of the greenstone belt, and amphibolite facies close to the contact with the Western Granodiorite. Previous work elsewhere in the Yellowknife area (e.g., Folinsbee, 1942; Henderson, 1943) showed that the metamorphic history of the area involved first regional metamorphism under moderate confining pressure, and secondly superimposed thermal metamorphism around late potassic granites such as the Prosperous Lake Granite described by Ramsay (1973). At the lowest grades chlorite-muscovite schists give way to large areas of biotite zone rocks. This zone is abruptly terminated by the cordierite isograd (Ramsay, 1973). There is also commonly evidence of a phase of hydrothermal retrogression following the two main prograde metamorphic events.

E. STRUCTURE

Northerly to northeasterly trends are dominant in the southern part of the Slave Province (see fig. 1). The volcanic piles of the Yellowknife Supergroup characteristically occur as homoclinal sequences facing away from bounding granitic rocks. They are little affected by folding

but have yielded to deformation by shearing. In contrast, the sedimentary rocks have been folded into intricate patterns of crossfolds. Most authors relate periods of deformation to periods of granitic intrusion.

Jolliffe (1942, 1946) first described the geology and structure of the Yellowknife area in some detail. He noted that the Kam Formation greenstones were relatively undeformed - apart from shear zones striking about north-northeast - and that the meta-sediments on the east side of the bay were complexly folded. Jolliffe recognized a major, northeast-plunging syncline underlying Yellowknife Bay, its axial trace extending from the mouth of the bay north to Burwash Point. He thought the feature was asymmetrical to this point, with its western limb a simple homocline, dipping and facing southeast, and its eastern limb overturned and partly folded into a subsidiary anticline. Jolliffe related these folds to two periods of folding deformation. Initial folding accompanied the emplacement of either the Western Granodiorite or the Southeastern Granodiorite, or both; the complicated cross-folding in the meta-sediments was due to the intrusion of the Prosperous Lake Granite. Campbell (1947) agreed with this interpretation, holding that the syncline was the oldest structure present. Later stages of deformation were apparently accompanied by subsidiary folding in the incompetent rocks east of Yellowknife Bay and the development of thrust faults or shear zones in the relatively competent greenstones to the west. Following Jolliffe, Campbell attributed the intricate pattern of refolding to the intrusion of the granitic bodies. The shear zones of the volcanic greenstones trend a little east of north, approximately

parallel to the general trend of the greenstones. Away from the shears the mafic volcanic rocks are not significantly disturbed.

Henderson (1970, 1971) and Hoffman and Henderson (1972) again related the cross-folds to intrusion of the Prosperous Lake Granite, and the shear zones of the Kam Formation to early faulting. However, they proposed that the syncline was an isoclinal feature extending northwards through Yellowknife Bay and beyond (fig. 2). Hoffman and Henderson (1972, p. 12) described the fold as being "horizontal to gently canoe-shaped", and slightly overturned to the west. The Kam and Jackson Lake Formations are exposed on the west limb, and the Duck and Burwash Formations are found only on the east limb. The Banting and Walsh Formations occur on both limbs north of the bay.

Ramsay (1973) presented no new evidence, but was guarded in his acceptance of the importance of the Yellowknife Bay syncline. He suggested that the syncline may be a much smaller structure than had been previously proposed. Within the meta-sediments he found little evidence of the sub-horizontal isoclinal folding reported by various authors elsewhere in Yellowknife Supergroup rocks. Ramsay distinguished five meta-sedimentary areas of differing structural patterns. In one, east and northeast of Yellowknife Bay, he thought folding was due to the emplacement of the Western Granodiorite; another he found had been deformed by the emplacement of the Prosperous Lake Granite, while a third appeared to have been affected by the intrusion of both bodies. The structural patterns of the last two areas he ascribed to interference from at least two of the bodies mentioned above.

Ramsay's ideas on Archean tectonism were based to a large degree on the models of Glikson (1972) and Anhaeusser, et al. (1969). Following Clifford (1972), Ramsay envisaged horizontal swelling of the plutons (as they rose diapirically) squeezing and deforming the intervening supracrustal rocks in a "keel".

Fyson (1975) studied the deformation of Yellowknife Supergroup metasediments in the Ross Lake-Gordon Lake area east of Yellowknife. He found three phases of folding had affected the greywacke rocks. Also, F_2 and F_3 had been accompanied by two periods of schistosity development. Large linear F_1 flexures are partly concordant with the bounding granitic complex. Upright, open to isoclinal F_2 folds vary somewhat and curve in their trend. They have an S_2 axial planar schistosity. Fyson believed that these F_1 and F_2 folds were developed mainly as gravity structures during diapiric uprise of the granitic basement.

Although F_3 folds are small-scale structures and are locally absent they are accompanied by a steep S_3 axial plane schistosity. To account for the F_3 folding, Fyson proposed a regional horizontal flattening that is possibly related to horizontal movements of early plates. With the model of Anhaeusser, et al. (1969) in mind, Fyson speculated that the change to F_3 folding reflects the transition from a regime where deformation was largely controlled by movements induced by local density contrasts within a mobile crust, to a regime where large segments of the crust moved horizontally to produce regional horizontal compression.

The last important tectonic event was the development of a series of sinistral, steeply dipping to vertical, predominantly strike-slip faults (Hoffman and Henderson, 1972). The most prominent of these is

the West Bay fault whose dip- and strike-slip displacements are about 480 m and over 4900 m, respectively (Campbell, 1948). The late faults are characterized by the development of a fault breccia or a clay gouge. A narrow fissure is the normal topographic expression, and even in the largest fractures the fault zone is rarely more than a meter wide. Sporadic iron-staining occurs in a stockwork of minute fractures extending some distance from the fault. Quartz veins and lenses are locally found along the faults. Some of these contain a little pyrite and chalcopyrite and also ferruginous carbonate, but gold values are negligible (Henderson and Brown, 1966). In places, e.g., in the West Bay fault near its junction with the Akaitcho fault, extreme silicification has resulted in the development of 30 m wide 'giant quartz veins'.

Strain ratios in the order of 50:1 or more and transcurrent movement in excess of 100 km are typical of Archean mobile belts at infracrustal levels in SW Greenland and NW Scotland (Bridgwater, et al., 1973; Coward, et al., 1973; Escher and Watterson, 1974). Some of these linear belts possibly extend for several thousand kilometers (Sutton, 1975). At higher levels the strain has been dissipated by non-penetrative deformation. Glikson (1970) determined strain ratios of about 3:1 for the Kurrawang beds of the Kalgoorlie greenstone belt of Western Australia, thought by many to be very similar to the Yellowknife greenstone belt. This study shows the main Giant shear zone has a strain ratio of about 8:1.

F. DISCUSSION

Greenstone belt formation is associated with some form of fracturing of an older gneissic basement and the upwelling of mantle-derived material (e.g., Windley, 1972). Many authors compare Phanerozoic plate-

tectonic models with the tectonics of the early Precambrian (e.g., recently, Tarney, et al., 1975). This may or may not be valid. Remobilization of basement along mobile zones (Bak, et al., 1975; Coward, et al., 1973; Coward, et al., 1975; Sutton, 1975) saw general regional metamorphism and diapiric granitic (s.l.) plutonism (Ramsay, 1973). It is conceivable that the shear zones at Yellowknife were initiated early on during plutonism as gently dipping planar belts (Escher and Watterson, 1974), and were uplifted and tilted and underwent further deformation during diapir emplacement. The supracrustal rocks between the rising diapirs were deformed and flattened (Clifford, 1972). As weaknesses within the main rock body, the shear zones were exploited by migrating gold-chloride complexes during amphibolite facies metamorphism (Fyfe and Henley, 1973; Fripp, 1975).

With uplift and unroofing and a reduction in pressure and temperature, ductile deformation in the shear zones gave way to more brittle fracturing - as evidenced by the conjugate joint set at Giant. A relaxation of compression would have occurred when the bounding granitic plutons stopped rising and began to cool.

Chapter III

GEOLOGY OF THE GIANT MINE AREA

A. GENERAL STATEMENT

The Giant Mine property is underlain by various basic to intermediate volcanic flows and associated cherty and slaty tuffs and interflow breccias. The homoclinal sequence is overturned and dips steeply westwards. The original volcanic pile is intruded by numerous irregular gabbroic masses and diabase dykes and sills, the youngest of which are younger than the gold-bearing schists. On the east side, adjacent to Yellowknife Bay, the flows are overlain by arkosic conglomerates, quartzites, greywackes and tuffaceous beds. To the west the volcanic rocks are terminated by the West Bay fault and the Western Granodiorite. Gold-ore occurs in a system of schistose shear zones which strike generally subparallel to the stratigraphy, but which in dip-direction cut across the volcanic units at various angles. The West Bay fault is a late fault that intersects the Yellowknife greenstone belt at an acute angle, crossing the southern portion of the Giant claim group (see fig. 3). This fault marks the southern limit of the Giant ore system. The similar Akaitcho fault in the north marks the northern limit of the original Giant property.

B. STRATIGRAPHY

The volcanic pile comprises a series of pillowed and massive andesite flows intruded by sills and irregular cross-cutting dykes of gabbro and diorite. The stratigraphy reported by Bateman (1952) has been

LEGEND

Stippled ornament and wavy lines: shear zone systems (1:Campbell; 2:Negus-Rycon; 3:Con; 4:Giant; 5:Bow Lake)

Oblique lines: Townsite-Brock flows

Horizontal lines: Jackson Lake Formation

Clear: Kam Formation

Short Lines: Western Granodiorite (WG)

Other Symbols:

AF	Akaitcho Fault	NF	Negus Fault
BC	Baker Creek	P	Pud Lake
CN	Con Shaft	PF	Pud Fault
F	Frame Lake	S	Stock Lake
G	Gar Lake	T	Trapper Lake
GT	Giant 'C' Shaft	TF	Townsite Fault
K	Kam Lake	WBF	West Bay Fault
KF	Kam Fault	YK	Yellowknife City
LI	Latham Island	YKB	Yellowknife Bay
MF	Martin Fault		

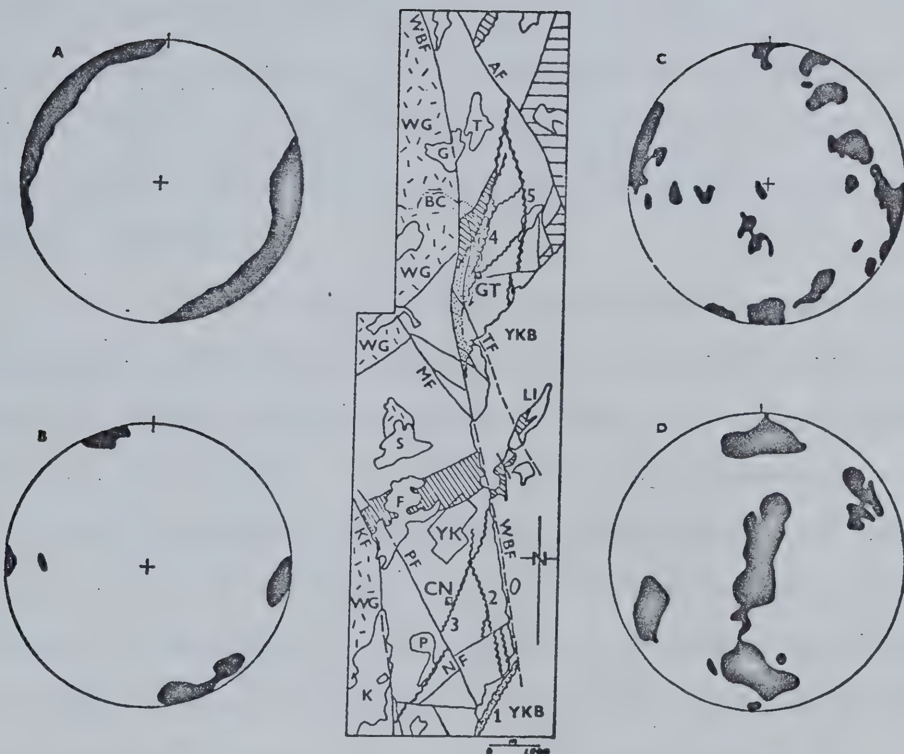

Fig. 3. Orientations of joints (A), faults (B), veins (C), fibres (D) near the 'C' Shaft of the Giant Mine.

replaced by that of Henderson and Brown (1966). Baragar (1975) correlated the surface geology of Henderson and Brown with subsurface diamond drill information, and reported that under Yellowknife Bay the Banting Formation consists of massive quartz and quartz-feldspar porphyry. Individual flows are difficult to distinguish. The lowermost 160 m of the Banting Formation includes alternating layers of porphyry and fragmental rock of similar material. The contact between the Banting volcanic rocks and the underlying Jackson Lake greywackes to the west is obscured by quartz-carbonate alteration that is typical of schistose parts of the Banting Formation.

On the surface the Jackson Lake Formation near the Giant Mine is a conglomeratic sandstone; underground it is composed largely of greywacke with little shale and no conglomerate (Baragar, 1975). Well-graded beds up to 8 m occur locally, but for the most part the greywackes are massive, monotonous units. In the lower part of the section are felsic pyroclastic units. One distinctive welded tuff horizon Baragar interpreted as an ignimbrite. Faulting and schist development mark the Jackson Lake Formation-Kam Formation contact, but little of the Jackson Lake Formation is thought to be missing (Baragar, 1975).

Baragar (1975) noted that in the segment of the Kam Formation he examined, the pillowed units are continuously pillowed and have no evidence of a hiatus in their course of accumulation. One cherty layer separating a massive and pillowed flow is the only sign of a break in the eruptive sequence in the Giant Mine area (Baragar, 1975). The variolitic flows can be correlated with the Negus and Yellowrex flows of Henderson and Brown (1966). Baragar's section does not extend west of the Giant millsite and 'C' Shaft.

Immediately west of the millsite is the Baker Creek valley in which outcrop is very limited. Andesitic pillowed and massive flows of variable schistosity are known from underground workings beneath the creek (Bateman, 1952; Henderson and Brown, 1966). Cropping out to the west of the Baker Creek valley is the Brock unit (Bateman, 1952). Equivalent to the Townsite flows of Henderson and Brown (1966), the Brock unit comprises mainly porphyritic quartz-feldspar dacite, agglomerate and tuff. The Townsite-Brock unit is a distinctive marker in the Yellowknife area, and similar feldsparphyric rocks are known from other Archean greenstone belts (Green, 1975). Adjacent to the Western Granodiorite are the lowermost units of the Kam Formation. They include relatively massive flows of variolitic, pillowed and massive basalts and andesites (Brown and Dadson, 1953; Henderson and Brown, 1966).

C. METAMORPHISM AND MINERALIZATION

Regionally, Boyle (1961) found that the metamorphic facies of the greenstone belt at Yellowknife are related to the Western Granodiorite-greenstone contact. The zoning includes an amphibolite facies adjacent to the granodiorite, a broad central epidote amphibolite facies, and an irregular and ill-defined greenschist facies farthest from the granodiorite. Isograd lines are not sharp and transition zones are the rule (Boyle, 1961). In the area of the Giant Mine, strike-slip faulting along the West Bay fault has brought the central epidote amphibolite facies against the granodiorite and Boyle's amphibolite facies is absent.

Boyle believed the metamorphic facies represented a prograde sequence. His analyses (Boyle, 1961) show a consistent increase of water, carbon dioxide and sulphur toward the lower grade facies, i.e., outward from the granodiorite. He suggested that these compounds, initially present in the rocks, were mobilized during regional metamorphism and migrated into the cooler zones.

Superimposed on this regional metamorphism is the system of shear zones and their associated alteration products. Within the greenstones a gradation exists from massive or slightly schistose greenstone through chlorite schist and chlorite-carbonate schist to the innermost parts of the schist zones where the rock is very strongly schistose. A typical schist assemblage includes sericite, chlorite and carbonate minerals, and quartz and albite. The mineral assemblage in unfoliated greenstone is epidote-carbonate-fibrous amphibole-chlorite-plagioclase.

Gold mineralization in the shear zones tends to be localized where dilatant zones have formed allowing silicification, sericitization and the deposition of the ore minerals (Boyle, 1961). The gold ore is concentrated in the central, sericitic parts of the schists which are shot through with irregular quartz lenses and stringers and are mineralized with sulphides, sulphosalts and gold. The ore shoots comprise quartz, sericite-carbonate schist and common pyrite, arsenopyrite, sphalerite and chalcopyrite, as well as sulphosalts, pyrrhotite, aurostibnite and gold (Coleman, 1957). More often than not, the shoots have an envelope of sericite and chlorite schist that grades into the chlorite schist of the host schist zone. The irregular masses, pods and stringers of quartz are intermixed with patches of dragged and contorted sericite-carbonate schist.

Coleman (1957) reported that the metallic minerals were deposited during three separate periods of mineralization from hydrothermal solutions having a magmatic origin. He held that pyrite and arsenopyrite formed first with most of the gold. Sphalerite, chalcopyrite and minor pyrrhotite were formed during the second period of mineralization, and Pb and Sb sulphides and sulphosalts were the dominant minerals formed during the third and last period. Aurostibnite Coleman believed to be a reaction product. He thought the initial temperature of mineral formation, including that of the gold, exceeded 500°C.

Ramsay (1973) noted the common association of gold and sulphides in the vein deposits in the Burwash Formation around the Prosperous Lake Granite. This association he took to indicate that sulphide was the essential complexing agent for transporting gold. He found that the gold-quartz veins were deposited in dilatant zones. His fluid inclusion work showed that the deposits were formed by lateral secretion, that initial quartz vein formation occurred at around 250°C, but that sulphide and gold deposition took place at about 150°C. Ramsay did not investigate the gold deposits of the greenstones.

Whereas sulphur species and gold-sulphur complexes can provide a solution mechanism for gold at low temperatures, chloride systems may be much more important at high temperatures. Fyfe and Henley (1973) believed that gold is transported as an oxidized chloride complex. They argued that if water was expelled from amphiboles in the 500 to 700°C range, and if chloride was present, then most of the gold should move with the water in solutions undersaturated with respect to gold. They suggest that there would be a major dumping of gold between 300-400°C in the greenschist facies.

They noted that very steep thermal gradients are associated with diapirically rising plutons, that during active dehydration reactions there may be convective movement of fluids, and that during the passage of a rock from greenschist to amphibolite facies (400-500°C) "drastic mechanical events must occur" (Fyfe and Henley, 1973, p. 300). When chlorites and epidotes lose water and form new, less hydrous phases, the strain rates near the grains could lead to intense local micro-hydraulic fracturing with P_{fluid} exceeding P_{load}. At the same time, fluid could accumulate beneath relatively impermeable higher levels and ultimately penetrate them in shear zones and vein swarms. Fyfe and Henley thought this model might well fit many Archean schist-belt deposits and cited Mazoe in Rhodesia as an example. Yellowknife could be another (cf. Fripp, 1975).

D. STRUCTURE

On the Giant property the various units of the volcanic Kam Formation strike N10-42°* (Brown and Dadson, 1953). Between the West Bay and Akaitcho faults they are overturned and dip west at 65 to 85° (contrast this with the southeasterly dips and more easterly strikes of the same units west of the West Bay fault and northeast of the Akaitcho fault).

The gold-bearing schistose shear zones are economically the most important structural features (Brown, et al., 1959). Boyle (1961) also distinguished fractures whose relations indicate a pre-shear zone origin, and fractures initiated after the development of the shear zones.

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*all directions are given in degrees azimuth

1. Pre-Shear Zone Fractures

These are ubiquitous and conspicuous and many comprise en echelon sets. They commonly enclose discontinuous lenses of white and grey quartz up to 15 m long and 1 m wide. Contacts between the lenses and the wall-rocks are sharp and not associated with replacement or alteration. Near the Western Granodiorite the fractures and quartz lenses show no preferred orientation, but within the main part of the greenstone belt they strike N150°±10° (Boyle, 1961).

2. The Shear Zones

Concordant shear zones parallel the volcanics. They are narrow and discontinuous and are readily distinguishable from the cross-cutting discordant shear zones which attain hundreds of meters in width, several kilometers in length and which have localized the major economic gold-bearing quartz bodies. From the standpoint of internal structure, all gradations between "schist zones" and "breccia shear zones" are known to exist. All concordant and most discordant shear zones are schistose, comprising chlorite, chlorite-sericite, and sericite schists. The discordant Giant and Campbell systems are schistose.

Breccia shear zones, which are restricted to the most discordant shear zones such as the Con and Negus-Rycon systems (Boyle, 1961), contain elongate rock fragments, normally massive to slightly schistose in character and rarely more than 150 mm across. The fragments are cemented by such carbonate minerals as calcite and ankerite, and buff-coloured alteration zones accompany any local quartz lenses. In the transition from breccia shear zone to schist the breccia fragments become progressively obliterated. Although this transition can be seen in many schist

zones, in others no such genetic origin can be evoked and extensive brecciation was probably not important in their development (Boyle, 1961).

(a) Concordant shear zone systems. These are restricted to tuff horizons, flow contacts and incompetent lava flows. West of the West Bay fault the strike of the shear zones varies with the volcanic rocks from northeast to east. East of the West Bay fault the strike varies from due north to N20°, but northeast of the Akaitcho fault it is about N40°.

The concordant shear zones are schistose: commonly the schistosity is contorted. In places slivers of relatively undeformed rock are caught up in the schists. All contain quartz veins and lenses, but few give high gold assay values. Boyle (1961) noted that mineralization is confined to where the schistosity has been dragged or contorted, particularly at gentle flexures and at shear zone junctions. Quartz stringers occur within uncontorted shear zones apparently unrelated to internal structure. Boyle suggested these were formed in open dilatant zones localized by structures in the walls of the shear zones.

(b) Discordant shear zones.

(i) The Con System extends from near the Yellowknife townsite south to the Kam fault. The southern half of the Con system southwest of the Pud fault is a single shear zone but northeast of the Pud fault a number of minor shear zones split off the main zone, each eventually cut by the West Bay fault. These smaller zones are breccia shear zones containing small, high-grade gold-quartz lenses, mineralized with various sulphides and gold. However, the wide part of the main shear zone contains the major economic mineralization. At its widest the Con zone reaches 30 m in width and splits and rejoins around relatively massive

undeformed "horses" of country rock both along strike and parallel to dip. There are many shear zone junctions, and intense dragging and contortion of the schist has been affected (Boyle, 1961).

The mean strike of the Con system is N8° and the average dip 53°W. However, though the schistosity within the shear zones is essentially parallel to the walls of the shear zones, it dips 10° more steeply. Henderson and Brown (1966) support Campbell's (1949) hypothesis that the Con system originated by movement along a thrust fault. If this is so the west (hanging) wall has moved up about 300 m, and has had only a small southwards component.

(ii) The Negus-Rycon System comprises several 2 m wide shear zones striking southeast and dipping moderately westwards. They join the Con system near Rat Lake and are offset by the northeast-striking Negus fault. The shear zones contain breccia and schist, both of which occur from place to place along the margins of meta-gabbro and meta-diorite dykes that parallel the shear zones.

Field relations locally indicate a total strike separation of about 200 m along the shear zones. However, the main component of movement shifted the hanging wall up. Henderson and Brown (1966) suggested the Negus-Rycon system was produced at the same time as the Giant, Campbell and Con systems.

(iii) The Campbell System crops out beneath Yellowknife Bay west of the West Bay fault and roughly parallels the shoreline between Negus Point and Kam Point. Boyle (1961) obtained a mean strike and dip of N3° and 47°W, but the average strike and dip of the schistosity within the system are N6° and 63°W, respectively. This suggests that the western (hanging) wall moved up and southwards (Boyle, 1961). The system

comprises a number of interlacing chlorite schist zones locally reaching 130 m in width. The intervening horses are composed of slightly schistose greenstone as much as 65 m across.

(iv) The Giant System, which lies east of the West Bay fault, strikes north-northeast, cropping out beneath the drift-filled Baker Creek valley (fig. 3). Sinistral faulting along the Akaitcho fault brings the continuation of the system out at Gold Lake, from where it has been traced northeast through Vee Lake to Jackson Lake. On the surface the system forms a pattern with subparallel and branching schist zones separated by massive to slightly schistose rock. Along the eastern sides of the shears, subsidiary schist zones have a tendency to feather out into the wall-rocks and die away. Horses of more competent rock stand up between the wide schist zones which have suffered greater erosion and whose surface outcrops lie beneath drift-filled topographic depressions. Contacts between schistose and massive rock are gradational over many meters. Pillows, dyke contacts tuff bands and similar such features that can be distinguished in the massive rocks are destroyed in the schist zones (Boyle, 1961; Henderson and Brown, 1966).

Shear zone junctions, flexures in the walls, and drag folded parts of the shear zones control development of quartz veins and lenses and the irregular silicified ore-bodies. The greatest buckling, mashing and most extreme contortion of the schist occurs at the shear zone junctions. Boyle (1961) believed the main causes were movements along the shear zones, rotation of the less schistose horses between shear zones, and the wedging and buttress effect at the noses of horses. Thus greatest dilatancy occurred at the junction of two shear zones, in drag folds and near flexures in the wall-rocks. These being regions

of low pressure and low chemical potential, they tended to be the sites to which migrating elements moved, and the sites at which they were precipitated.

(v) The Bow Lake System lies east of, and is subsidiary to, the Giant system. It dips moderately westwards. South of Bow Lake it follows a drift-filled valley and is exposed near the shore of Yellowknife Bay as a 7 m wide zone of strongly foliated chlorite schist. North of Bow Lake it splits into several schist and breccia shear zones which merge into the Giant system.

(vi) The Stock and Handle Systems comprise a series of 1 meter wide shears that reach the surface west of the West Bay fault, west of the Giant Mine Camp. Both systems strike north to northeast and dip vertically or steeply to the west. They occur in the same sequence of lavas, are limited in their extent, and contain small quartz lenses and veins, some of which contain gold. One group of shears cuts across the amphibolitic greenstones, several irregular granitic masses, and a number of aplite and granitic dykes. Elsewhere, concordant and discordant shear zones contain aplite and granite dykes that show little or no evidence of shearing. Other shear zones, however, contain similar dykes that have been sheared and which contain lenses and stringers of gold-bearing quartz. One shear zone crosses the greenstone-granodiorite contact (Henderson and Brown, 1966). It seems that an early period of shearing provided an avenue for the emplacement of granitic bodies, and that some of these were affected by a later period of shearing. The shear zone systems were therefore apparently initiated at about the time of granodiorite intrusion, but shearing continued for some time afterwards.

(vii) The Crestaurum System occurs in the area east of Ryan Lake. Several shear zone branches combine to form a complex system rather like the Con system (Boyle, 1961).

3. Post-Shear Zone Fractures

These can be divided into those initiated prior to diabase intrusion, and those that are post-diabase intrusion.

Pre-diabase fractures that cut the shear zones are of many generations. They are numerous in all shear zones but most occur in or about ore zones (Boyle, 1961). Strikes are variable but most dip approximately normally to the schistosity to form a characteristic ladder structure. All contain quartz and carbonate minerals in short, narrow, irregular bodies, some of which carry sulphosalts and gold. The contacts of the quartz and wall-rock are sharp, and replacement features and wall-rock alteration zones are absent. These fractures, restricted to the shear zones, appear to be the result of tension during a late extension deformation period.

Post-diabase fractures include the major, late Proterozoic sinistral fault systems that meet at Yellowknife (Brown, 1955). Examples of these include the West Bay, Kam-Pud and Hay-Duck faults. Cross-over faults include the Akaitcho, Martin, Townsite and Aye faults. Many smaller, unnamed faults occur between the larger ones.

Chapter IV

DATA COLLECTION

A. SELECTION OF LOCALITY

At the outset of the investigations it was decided that a three-dimensional picture was desirable in order to best gain an insight into the structure and structural relations of the major Giant Mine shear zone. In this respect the most attractive part of the mine appeared to be that near the 'C' Shaft. Being the major shaft of Giant's operation the shaft also had access to all levels of the mine, and at the time the study was undertaken there was relatively little in the way of nearby mining operations that might otherwise have been a hindrance.

The levels that were eventually chosen for study are designated 950, 1100, 1250 and 1500, very roughly corresponding to their depth in feet below the 'C' Shaft headframe (fig. 4). Stopes that had been opened up near the 'C' Shaft could not be examined because either they had been filled in or blocked, or their walls were covered in a thick layer of mud, and so no traversing was attempted in them. On the 950 Level, the lack of cross-cuts near the shaft confined the study to the one major drift on the west side of the shear zone. The 1100 and 1250 Levels, with fairly extensive cross-cuts normal to the shear zone and a certain amount of drifting on the east side of the shear, offered excellent access. Although the 1500 Level was partly back-filled and many of its passages blocked off by bulkheads, it did afford limited opportunity for investigation across the shear zone.

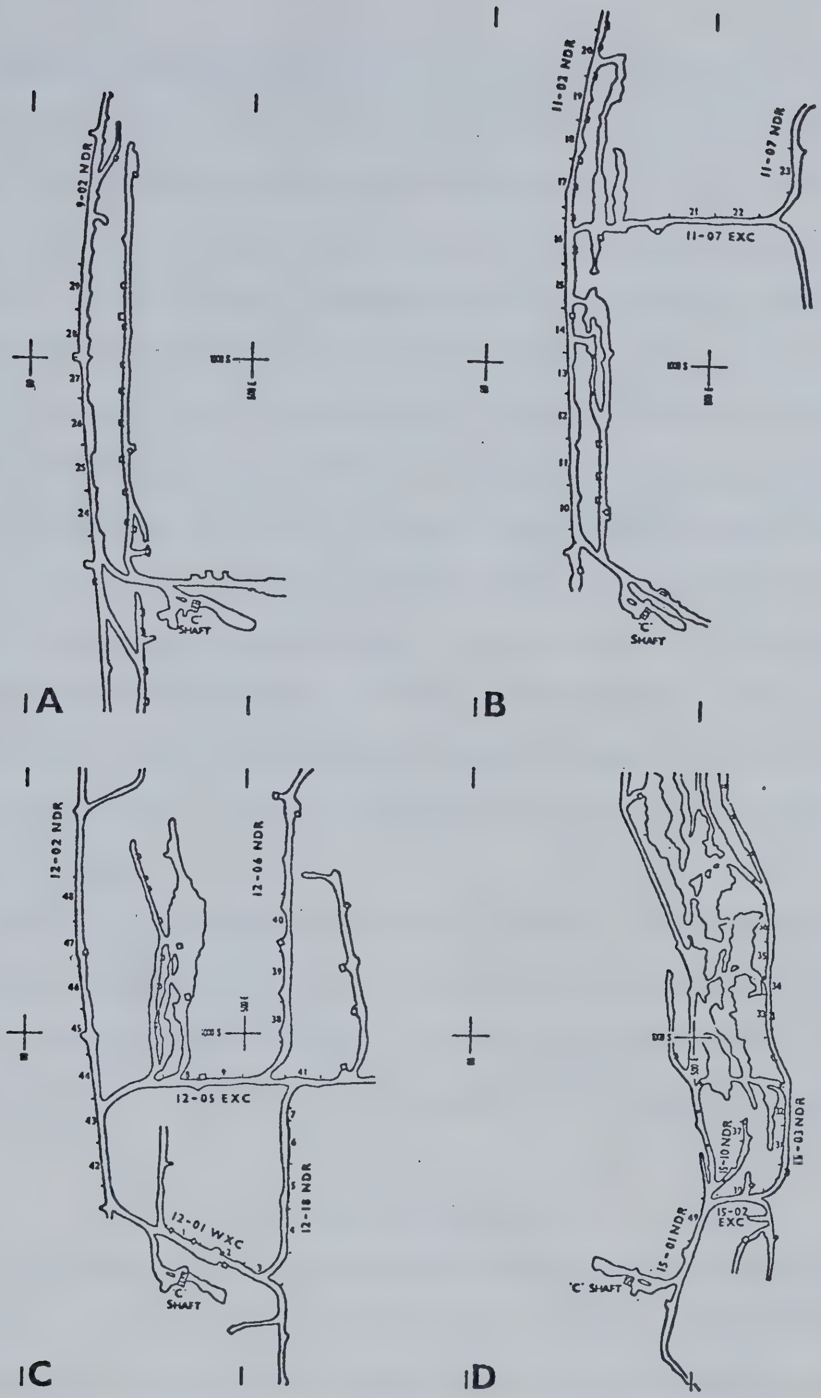


Fig. 4. Plans of the four levels near the 'C' Shaft. A: 950 Level; B: 1100 Level; C: 1250 Level; D: 1500 Level. (NDR: North Drift; EXC: East Cross-cut; numbers refer to traverses; Giant Mine grid in feet).

Work commenced on the 1250 Level along the 12-01 West Cross-cut (12-01 WXC in fig. 4C), the 12-18 North Drift and the 12-05 East Cross-cut. Although the traverses were interrupted by a number of ore passes, waste passes and service raises, nine traverses were completed. Work on the 1100 Level (fig. 4B) progressed along the 11-02 North Drift, the 11-07 East Cross-cut and the 11-07 North Drift. The study on the 1100 Level was interrupted several times by blasting, and the ensuing dust cloud terminated work each time! The structures along the 9-02 North Drift on the 950 Level (fig. 4A) were studied next, and were followed by eight traverses on the 1500 Level (fig. 4D), mainly along the 15-03 North Drift, but also in the 15-02 East Cross-cut and the 15-10 North Drift. Returning to the 1250 Level, 3 traverses were completed along the 12-06 North Drift, one in the 12-05 East Cross-cut again, and seven along the 12-02 North Drift. The last traverse was along the 15-01 North Drift of the 1500 Level.

In total, more than 4500 feet of drift wall were examined in 49 traverses, of which six were on the 950 Level, fourteen on the 1100 Level, twenty on the 1250 Level, and nine on the 1500 Level. Thirty-two orientated rock samples were collected from the four levels of the mine.

B. COLLECTION OF DATA

Field data were collected during a series of straight line 100 ft traverses and (mainly) recorded on sheets originally designed to aid the collection of structural and lithological data for a study of slope stability in open pits. Three types of sheet were used. Traverse line sheets (type *01) were used to record information about each traverse,

such as the grid coordinates and elevation of the start, its direction, and the rock unit crossed. Non-penetrative planar structures observed along each traverse were described on discontinuity data sheets (type *02) according to type, orientation, size, association with mineral filling, and mesoscopic folding. Planar structures that were observed include joints, faults, and veins. Discontinuity data sheets were also used to record the orientation and type of linear structures, the name of the rock type, and the distance along the traverse at which observations were made. The lithology data sheet (type *03) was used to describe rock types (lithology, hardness and grain size) and penetrative planar structures (type, orientation, spacing, association with mesoscopic folding and lineation). The recording rules and the three types of sheet are given in the DISCODAT manual in the Appendix.

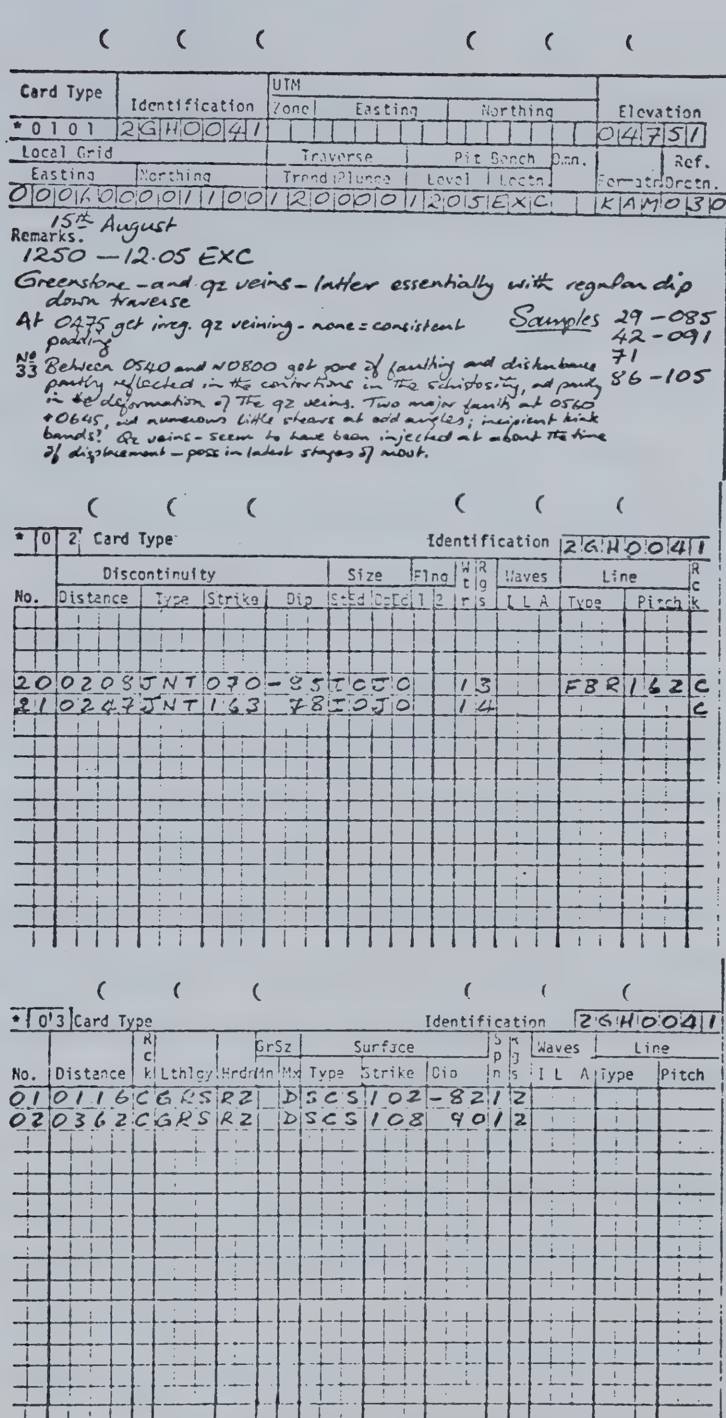
Ideally, the 100 ft tape should have been attached to the walls of the drifts and cross-cuts at a standard height, and the attitude of the structures under consideration measured at the point where they, or their presumed extensions, crossed the tape. This proved to be impractical so the tape was laid on the ground. Measurements were taken of those structures that crossed an imaginary waist-high line.

All structures were measured using a Rabone Chesterman No. 1190 boxwood carpenter's rule. Although not a precision instrument, it is quite adequate for the purposes required. The rule is marked in inches, and fractions thereof, and whereas it measures 2 ft when fully extended, its three hinges enable it to be folded into an instrument little more than 6 inches long. The two outer hinges serve no function bar that of convenience. The middle one, however, is scaled in units of 5° to allow

angular measurement. The clinorule's other important accoutrement is a small spirit level set into one of its 'arms'. This allows the determination of a horizontal line.

The muddiness of the drift walls and the darkness of the mine at times combined to make detailed observation difficult. For instance, small linear structures on joint surfaces probably went unnoticed on many occasions, and it was not easy to determine subtle lithological variations in the uncertain light of a miner's lamp. The penetrative (mineral) schistosity, too, was difficult to observe: joints that had developed as a response to the schistosity, rather than the schistosity itself, were measured. Thus, whereas observations on the penetrative schistosity were rarely entered on the lithology data sheet, there are many readings entered on the discontinuity data sheet of joints of a finely-spaced, parallel joint set that reflects the inherent schistosity.

Fig. 5 shows the three field sheets, partly filled in, for traverse number 41. In fig. 5A note that the Universal Transverse Mercator (UTM) system of coordinates was not used, and neither were the spaces allotted to "Domain" (Dmn). Under "Identification", 2GH indicates the year (1972) and the geologist's initials, and 0041 shows it is the 41st traverse. "Elevation" refers to the start of traverse, being in tenths of feet relative to the Giant Mine datum. The "Local Grid" is again Giant's, and figures entered are in feet. Note, however, that "Northing" in this case actually represents the distance <u>south</u> of an east-west base line. "Traverse Trend" is relative to True North. As this is an underground mine the terms "Pit Bench Level and Location" are redundant, but the traverse is still located by 4 numerals and 3 letters: 1205EXC



A

Card Type	Identification	UTM Zone	UTM Easting	UTM Northing	Elevation
*0101	2GH0041				04751

Local Grid Easting	Local Grid Northing	Traverse Trend	Traverse Plunge	Pit Bench Level	Pit Bench Loctn.	Dmn.	Formatn.	Ref. Orctn.
000160	000111	001	120	000	01205	EXC		KAM030

Remarks. 15th August
1250 — 12.05 EXC
Greenstone – and qz veins – latter essentially with regular dip down traverse
At 0475 get irreg. qz veining – none = consistent padding
No 33 Between 0540 and N0800 get zone of faulting and disturbance partly reflected in the contortions in the schistosity, and partly in the deformation of the qz veins. Two major faults at 0560 + 0645, and numerous little shears at odd angles; incipient kink bands? Qz veins – seem to have been injected at about the time of displacement – poss in latest stages of mout.

Samples 29 – 085
42 – 091
71
86 – 105

B

*02 Card Type — Identification 2GH0041

No.	Discontinuity Distance	Type	Strike	Dip	Size StEd	Size DcEc	Flng 1	Flng 2	Wtr	Rgs	Waves I L A	Line Type	Line Pitch	Rck
20	0208	JNT	070	-85	TC	JO			1	3		FBR	162	C
21	0247	JNT	163	78	IO	JO			1	4				C

C

*03 Card Type — Identification 2GH0041

No.	Distance	Rck	Lthlgy	Hrdr	GrSz Mn	GrSz Mx	Surface Type	Strike	Dip	Spn	Rgs	Waves I L A	Line Type	Pitch
01	0116	C	GRS	RZ		D	SCS	102	-82	1	2			
02	0362	C	GRS	RZ		D	SCS	108	90	1	2			

Fig. 5. Field sheets. A: type *01, the traverse line sheet; B: type *02, the discontinuity data sheet; C: type *03, the lithology data sheet.

indicates the traverse is in the 1205 East Cross-cut on the 1250 Level. The letters KAM identify the formation, being the name given to the Yellowknife greenstones by Henderson (1970). "Reference Direction" is the angle to be added to the recorded strike of an observed discontinuity in order to convert it to a dip-direction relative to True North (see DISCODAT manual in Appendix). (Note that strike as measured by the clinorule is measured relative to the trend of the traverse - see below.)

Under "Remarks" any other information not accounted for can be noted, and in fig. 5A comments are made regarding the quartz veining encountered on the traverse, and the contorted schistosity between 54 and 80 feet from the start of the traverse. A sketch of the structure at 62.3 feet was made on the reverse of the sheet. Four samples, three of them orientated were collected from this traverse, at distances 29, 42, 71 and 86 feet from the start.

Although for each traverse just one *01 data sheet is used, the number of *02 data sheets for each traverse is dependent on the number of "discontinuities" observed along the traverse. Fig. 5B shows lines 20 and 21 from the second discontinuity data sheet used for traverse 41. "Identification" is the same as in data sheet *01 (fig. 5A). Under "No." a sequence number is entered, beginning with "01" for the first observation on the first *02 data sheet; numbers "17" through "32" are entered on the second *02 data sheet.

Consider observation number 20. At a distance 20.8 feet from the start of the traverse a joint ("JNT") was measured that has a strike, relative to the trend of the traverse, of 70°, and a dip of 85°. The minus sign indicates the dip-direction is essentially towards the start

of the traverse. Contrast this with observation number 21. At a distance 24.7 feet down the traverse there is a joint with a strike of 163° and a dip of 78°. The absence of a minus sign before the dip value indicates that the surface dips essentially <u>down</u> the traverse.

Note that the distance is measured and recorded on the data sheets in units of tenths of feet, and that the 'Type' of discontinuity observed is recorded as a 3-letter mnemonic (see section 1.6 of the manual in Appendix). The 'size' of the discontinuity was recorded with respect to size parallel to the strike (St) and parallel to the dip (Dp) on a 0, 1, 2 scale such that 0 indicated the observed surface was small and confined to the limits of the drift, 1 indicated one end was visible, and 2 that the surface was large and neither end was visible. The letters give an absolute measure of the size of the discontinuity (see section 1.7 of the manual in Appendix). The two most important mineral fillings (if any) are entered under "Flng". For "Wtr" (water) a scale of 1 to 6 is used, 1 indicating the discontinuity is tight, and 6, that the water is actually flowing along it. A 1 to 5 scale for roughness of the surface is entered under "Rgs". If a waviness is present, the interlimb angle ("ILA") is entered. Linear structures are recorded under "Line", by "type" ("FBR" being the mnemonic for a fibrous lineation) and "Pitch" being measured clockwise on the surface from the right-hand end of the strike line to the linear. In sequence beginning with A the different rock types encountered are entered under "Rck". They are more fully described on the lithology data sheet.

Fig. 5C shows lithology data sheet *03 for traverse 41 with the first line filled in. A sequence number records the lithologies observed,

and "Distance" is entered as in data sheets *02. Rock type C was a greenstone, entered as the mnemonic "GRS" under "Lthlgy". Refer to the manual (Appendix) for a detailed description of the classification used to define the hardness ("Hrdn") of the rock. "R2" in this instance indicates "soft rock". Grain size ("GrSz") uses a modified Wentworth scale to define the finest ("Mn") and coarsest ("Mx") 10% of grains is the rock. "SCS" for the penetrative "surface type" indicates a schistosity was observed. Strike and dip follow identical recording rules as surface type on *02 data sheets. The average spacing ("Spn") follows the grain size scale, and roughness ("Rgs"), "Waves and Line" have their counterparts on *02 data sheets, described above.

Since the study was undertaken DISCODAT has been revised and modified somewhat. The manual in the Appendix is that used in this study. The latest edition of the manual can be obtained from Dr. D.M. Cruden, Department of Geology, University of Alberta.

Chapter V

DATA PROCESSING

A. INTRODUCTION

A data file was built using the program CONVERT3 (Ramsden, 1975). Retrievals from this data file were accomplished using the program KEY4 (Ramsden, 1975). Ramsden's programs are documented in his thesis which should be consulted for a listing of them and the subroutines they call. The data file can be obtained from Dr. H.A.K. Charlesworth, Department of Geology, University of Alberta.

B. EDITING AND STORAGE

The information on each data sheet was punched onto computer cards. A list of all cards was used to check the data and new cards were punched where required. The edited cards were then fed into the computer. Combining data on field sheet types *02 and *03, CONVERT3 (Ramsden, 1975) produced the file GH.CARDS. Fig. 6 is a display of part of this file. In this file, line 1 of each traverse represents the traverse line data sheet (type *01) with some additional information common to the whole traverse (see line 1391 of the printout in fig. 6). The format of the line 1 record is shown in Table 1.

The first field of four columns identifies the traverse line sheet. The year and the geologist's initials occupy the first 3 columns of the traverse identification field. 'Elevation', 'Mine Grid Easting' and 'Mine Grid Northing' reference the start of the traverse relative to the 'Traverse Length' which is in tenths of feet.

The format of the type 2 record (field sheets *02 + *03 combined) is shown in Table II.

```
1376   *C228/0533/JN/010/ 63/A/ / / /1/   / /   /GRS/  /          2GH0040
1377   *C229/0533/JN/157/-81/B/ /C/ /4/   / /   /GRS/  /          2GH0040
1378   *C230/0610/FL/020/ 83/C/ /C/ /4/   /FB/180/GRS/  /          2GH0040
1379   *0231/0645/JN/047/-87/A/ / / /1/   / /   /GRS/  /          2GH0040
1380   *C232/0658/VN/177/ 85/C/ /Q/ /1/   / /   /GRS/  /          2GH0040
1381   *C233/0660/JN/172/-60/A/ / / /1/   / /   /GRS/  /          2GH0040
1382   *C234/0802/JN/051/ 80/C/ /C/Q/3/   /FB/008/GRS/  /          2GH0040
1383   *C235/0811/JN/175/-92/B/ / / /1/   / /   /GRS/  /          2GH0040
1384   *C236/0848/JN/070/-67/A/ / / /1/   / /   /GRS/  /          2GH0040
1385   *C237/0893/VN/128/ 82/C/ /Q/ /1/   / /   /GRS/  /          2GH0040
1386   *C238/0941/JN/055/ 78/C/ /Q/C/2/   / /   /GRS/  /          2GH0040
1387   *C239/0965/JN/137/-75/A/ /Q/C/1/   /FB/060/GRS/  /          2GH0040
1388   *C240/0973/JN/060/-70/A/ / / /1/   / /   /GRS/  /          2GH0040
1389   *C241/0984/JN/055/-67/A/ / / /1/   / /   /GRS/  /          2GH0040
1390   *C242/0990/JN/162/-76/A/ / / /1/   / /   /GRS/  /          2GH0040
1391   *0101/2GH0041/C4751/  /KAM/1205/EXC/000600/001100/120/000/ 977/0/53/030/
1392   *C201/0031/VN/052/ 55/C/ /Q/ /1/   / /   /GRS/R2/          2GH0041
1393   *C202/0034/JN/137/-83/A/ / / /1/   / /   /GRS/R2/          2GH0041
1394   *C203/0045/JN/079/-47/B/ / / /2/   / /   /GRS/R2/          2GH0041
1395   *C204/0048/VN/115/ 45/C/ /Q/ /1/   / /   /GRS/R2/          2GH0041
1396   *C205/0058/JN/068/ 68/A/ / / /1/   / /   /GRS/R2/          2GH0041
1397   *C206/0067/JN/120/ 82/A/ / / /1/   / /   /GRS/R2/          2GH0041
1398   *C207/0089/JN/151/-80/B/ /Q/C/2/   /FB/170/GRS/R2/          2GH0041
1399   *C208/0098/JN/150/-77/A/ / / /1/   / /   /GRS/R2/          2GH0041
1400   *C209/0100/JN/140/ 38/A/ / / /1/   / /   /GRS/R2/          2GH0041
1401   *C210/0105/JN/056/ 84/A/ / / /1/   / /   /GRS/R2/          2GH0041
1402   *C211/0106/JN/150/ 90/A/ / / /1/   / /   /GRS/R2/          2GH0041
1403   *C212/0108/JN/065/-60/B/ /Q/C/2/   /GV/151/GRS/R2/          2GH0041
1404   *0213/0143/VN/128/ 75/C/ /Q/ /1/   / /   /GRS/R2/          2GH0041
1405   *C214/0166/VN/139/ 65/C/ /Q/ /1/   / /   /GRS/R2/          2GH0041
1406   *C215/0171/VN/055/ 29/C/ /Q/ /1/   / /   /GPS/R2/          2GH0041
1407   *C216/0179/JN/055/-80/C/ /Q/C/1/   /FB/167/GRS/R2/          2GH0041
1408   *C217/0180/JN/131/-85/A/ / / /1/   / /   /GRS/R2/          2GH0041
1409   *C218/0183/JN/053/-80/A/ / / /1/   /FB/163/GRS/R2/          2GH0041
1410   *C219/0200/JN/120/-89/A/ / / /1/   / /   /GRS/R2/          2GH0041
1411   *C220/0208/JN/070/-85/A/ / / /1/   /FB/162/GRS/R2/          2GH0G41
1412   *C221/0247/JN/163/ 78/A/ / / /1/   / /   /GPS/R2/          2GH0041
1413   *C222/C253/JN/059/-75/C/ / / /1/   /FB/156/GRS/R2/          2GH0041
1414   *C223/0269/VN/095/ 70/C/ /Q/ /1/   / /   /GRS/R2/          2GH0041
1415   *C224/C339/VN/090/-80/C/ /Q/ /1/   / /   /GPS/R2/          2GH0041
1416   *C225/C415/JN/067/-74/A/ / / /2/   /GV/153/GRS/R2/          2GH0041
1417   *C226/0428/JN/050/-76/A/ / / /1/   / /   /GRS/R2/          2GH0041
1418   *C227/0459/JN/049/-68/C/ / / /2/   / /   /GRS/R2/          2GH0041
1419   *C228/0490/JN/072/-70/C/ / / /1/   / /   /GRS/R2/          2GH0041
1420   *C229/0520/CN/093/ 77/C/ /Q/ /1/   / /   /GRS/R2/          2GH0041
1421   *C230/0523/CN/093/ 77/C/ /Q/ /1/   / /   /QTZ/  /          2GH0041
1422   *0231/C558/FL/065/-49/C/ / / /3/   / /   /GRS/R2/          2GH0041
1423   *C232/0623/KK/131/-14/B/ / / /1/   / /   /GRS/R2/          2GH0041
1424   *C233/0642/FL/099/-49/C/ /Q/ /3/   / /   /GRS/R2/          2GH0041
1425   *C234/0672/VN/071/ 59/B/ /Q/ /1/   / /   /GFS/R2/          2GH0041
1426   *C235/0715/KK/110/ 40/A/ / / /1/   / /   /GRS/R2/          2GH0041
1427   *C236/0733/KK/114/ 43/A/ / / /1/   / /   /GRS/R2/          2GH0041
1428   *C237/0781/VN/095/ 90/C/ /Q/ /1/   / /   /GRS/R2/          2GH0041
1429   *C238/0796/JN/130/-75/B/ / / /1/130/ /   /GPS/R2/          2GH0041
1430   *C239/0803/JN/052/-58/B/ / / /1/   /GV/013/GRS/R2/          2GH0041
1431   *C240/C806/JN/151/-71/A/ / / /1/   / /   /GRS/R2/          2GH0041
1432   *C241/0867/SF/037/ 59/C/ /Q/ /3/   / /   /GRS/R2/          2GH0041
1433   *C242/0874/JN/111/-86/A/ / / /1/   / /   /GRS/R2/          2GH0041
1434   *0243/0897/JN/067/ 89/A/ / / /1/   / /   /GRS/R2/          2GH0041
1435   *C244/0911/VN/086/ 88/C/ /Q/1/1/   / /   /GRS/R2/          2GH0041
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Fig. 6. Part of the printout of file GHCARDS. Figures on extreme left indicate line number. See Table I for explanation. * denotes first column.

Table I. Format of the line 1 record of GH.CARDS

Columns	Contents
7-13	Traverse Identification (A)
15-19	Elevation (Mine Datum)
21-22	Domain (A)
24-26	Formation (A)
28-31	Mine Level
33-35	Mine Location (A)
37-42	Mine Grid Easting
44-49	Mine Grid Northing
51-53	Traverse Trend
55-57	Traverse Plunge
59-62	Traverse Length
64	Traverse Scale
66-67	Number of Observations
69-71	Reference Direction

(A) denotes alphanumeric data

Table II. Format of the line 2 record

Columns	Contents
7-10	Distance
12-13	Type (A)
15-17	Strike (relative to traverse)
19-21	Dip
23	Size (A)
25	Spacing (A)
27	Filling 1 (A)
29	Filling 2 (A)
31	Water (A)
33-35	Waves
37-38	Linetype (A)
40-42	Line Pitch
44-46	Lithology (A)
48-49	Hardness (A)

(A) denotes alphanumeric data

'Distance' refers to distance from the start of the traverse and is recorded in tenths of feet. Whereas 'Type' is the planar feature under consideration, 'Linetype' refers to any linear feature that is present on the surface. The traverse is again identified in the last 7 columns.

The data were converted to the form shown in fig. 7 and a new file, GH.CONV, formed. Data file GH.CONV was built by the program CONVERT3 (Ramsden, 1975). In this form the data are ready for processing. For each traverse, CONVERT3 has combined the information general to the traverse (line 1 of each traverse of GH.CARDS) with the type 2 record data. (Note that when this survey was conducted, the 1972 DISCODAT manual (see Appendix) was effective. A revised (1973) manual incorporates innovations into the system, the major change being the adoption of only two field sheet forms. The result is that data are punched onto cards and fed into the computer in a form similar to GH.CARDS.) GH.CONV is a set of identical format data records, one for each observed discontinuity. GH.CONV(3) is an edited version of GH.CONV and is the 1788 line file used in the data processing. The format of GH.CONV allows for all information general to the whole traverse to be printed on each line for every observation in the traverse. Therefore all information pertaining to any single observation, general and specific, within that traverse is printed out on one line.

The format of the converted data records (see fig. 7) is described in Table III.

The direction cosines of the downward-directed normal to the discontinuity are given by a, b and g, and l, m and n are the direction cosines of the linear. If no linear was observed, l, m and n are set to

```
1321  D2GHC040  KAM1206NDR 30  C 99042036 848  6324  E48447510JN190 67 9065 1599 3907 12A   1                    0    0    OGRS
1322  D2GHC040  KAM1206NDR 30  0 99042037 893  6346  852347510VN 68 82-3710-9182 1392 13C Q 1                    0    0    OGRS
1323  D2GHC040  KAM1206NDR 30  C 99042038 941  6370  856547510JN355 78-9744  853 2079 12C OC2                   0    0    OGRS
1324  D2GHC040  KAM1206NDR 30  0 99042039 965  6382  858647510JN257 75 2173 9412 2588 15A OC1   FB-5376-1059 8365GRS
1325  D2GHC040  KAM1206NDR 30  0 99042040 973  6386  859347510JN180 70 9397    0 3420 12A   1                    0    0    OGRS
1326  D2GHC040  KAM1206NDR 30  0 99042041 984  6392  E60247510JN175 67 9170 -802 3907 13A   1                    0    0    OGRS
1327  D2GHC040  KAM1206NDR 30  0 99042042 990  6395  860747510JN282 7 -2017 9491 2419 33A   1                    0    0    OGRS
1328  D2GHC041  KAM1205EXC120  0 977530 1   31  6027 1098547510VN 82 5 -1140-8112 5736 15C Q 1                  0    0    OGRSR2
1329  D2GHC041  KAM1205EXC120  C 977530 2   34  6029 1098347510JN347 83-9671 2233 1219 15A   1                  0    0    OGRSR2
1330  D2GHC041  KAM1205EXC120  0 977530 3   45  6039 1097847510JN289 47-2381 6915 6820 14B   2                  0    0    OGRSR2
1331  D2GHC041  KAM1205EXC120  C 977530 4   48  6042 1097647510VN145 45 5792-4056 7071 16C Q 1                  0    0    OGRSR2
1332  D2GH0041  KAM1205EXC120  0 977530 5   58  6050 1097147510JN 96 88 1045-9939  349 11A   1                  0    0    OGRSR2
1333  D2GHC041  KAM1205EXC120  0 977530 6   67  6058 1096747510JN150 82 8576-4951 1392 12A   1                  0    0    OGRSR2
1334  D2GHC041  KAM1205EXC120  0 977530 7   89  6077 1095647510JN   1 80-9847 -172 1736 21B OC2   FB  130 9852 1710GRSR2
1335  D2GHC041  KAM1205EXC120  0 977530 8   98  6085 1095147510JN   0 77-9744    0 2250 21A   1                  0    0    OGRSR2
1336  D2GHC041  KAM1205EXC120  C 977530 9  100  6087 1095047510JN170 38 6063-1069 7880 25A   1                  0    0    OGRSR2
1337  D2GHC041  KAM1205EXC120  0 97753010  105  6091 1094847510JN 86 84 -694-9921 1045 12A   1                  0    0    OGRSR2
1338  D2GHC041  KAM1205EXC120  0 97753011  106  6092 1094747510JN180 90 9999    0    0 20A   1                  0    0    OGRSR2
1339* D2GHC041  KAM1205EXC120  0 97753012  108  6094 1094647510JN275 80 -858 9811 1736 11B OC2   GV 8786  -76 4774GRSR2
1340  D2GHC041  KAM1205EXC120  0 97753013  143  6124 1092947510VN158 75 8956-3618 2588 13C Q 1                  0    0    OGRSR2
1341  D2GHC041  KAM1205EXC120  0 97753014  166  6144 1091747510VN169 65 8897-1729 4226 17C Q 1                  0    0    OGRSR2
1342  D2GHC041  KAM1205EXC120  0 97753015  171  6148 1091547510VN 85 29 -423-4830 8746 25C Q 1                  0    0    OGRSR2
1343  D2GHC041  KAM1205EXC120  0 97753016  179  6155 1091147510JN265 80  858 9811 1736 12C OC1   FB 9673-1238 2215GRSR2
1344  D2GHC041  KAM1205EXC120  0 97753017  180  6156 1091047510JN341 83-9419 3243  872 13A   1                  0    0    OGRSR2
1345  D2GH0041  KAM1205EXC120  0 97753018  183  6158 1090947510JN263 80 1200 9775 1736 13A   1   FB 9430-1669 2879GRSR2
1346  D2GHC041  KAM1205EXC120  0 97753019  200  6173 1090047510JN330 89-6659 4999  175 12A   1                  0    0    OGRSR2
1347  D2GHC041  KAM1205EXC120  0 97753020  208  6180 1089647510JN280 85-1730 9811  872 11A   1   FB 9413 1386 3078GRSR2
1348  D2GHC041  KAM1205EXC120  0 97753021  247  6214 1087747510JN193 78 9531 2200 2079 35A   1                  0    0    OGRSR2
1349  D2GHC041  KAM1205EXC120  0 97753022  253  6219 1087447510JN269 75  169 9658 2588 12C   1   FB 9116-1212 3929GRSR2
1350  D2GHC041  KAM1205EXC120  0 97753023  269  6233 1086647510VN125 70 5390-7698 3429 11C Q 1                  0    0    OGRSR2
1351  D2GHC041  KAM1205EXC120  0 97753024  339  6294 1083147510VN300 80-4924 8529 1736 10C Q 1                  0    0    OGRSR2
1352  D2GHC041  KAM1205EXC120  0 97753025  415  6359 1079347510JN277 74-1171 9541 2756 11A   2   GV 8996 -156 4364GRSR2
1353  D2GH0041  KAM1205EXC120  0 97753026  428  6371 1078647510JN260 76 1085 9556 2419 13A   1                  0    0    OGRSR2
1354  D2GHC041  KAM1205EXC120  0 97753027  459  6398 1077147510JN259 68 1769 9101 3746 14C   2                  0    0    OGRSR2
1355  D2GHC041  KAM1205EXC120  0 97753028  490  6424 1075547510JN282 70-1954 9192 3420 11C   1                  0    0    OGRSR2
1356  D2GH0041  KAM1205EXC120  C 97753029  520  6450 1074047510CN123 77 5307-8172 2250 10C Q 1                  0    0    OGRSR2
1357  D2GHC041  KAM1205EXC120  0 97753030  523  6453 1073947510CN123 77 5307-8172 2250 10C Q 1                  0    0    OOTZ
1358  D2GHC041  KAM1205EXC120  0 97753031  558  6483 1072147510FL295 49-3190 6840 6561 13C   3                  0    0    OGRSR2
1359  D2GHC041  KAM1205EXC120  0 97753032  623  6540 1068947510KK341 14-2287  789 9703 55B   1                  0    0    OGRSR2
1360  D2GHC041  KAM1205EXC120  0 97753033  642  6556 1067947510FL309 49-4750 5865 6561 13C Q 3                  0    0    OGRSR2
1361  D2GHC041  KAM1205EXC120  0 97753034  672  6532 1066447510VN101 59 1635-8414 5150 12B Q 1                  0    0    OGRSR2
1362  D2GHC041  KAM1205EXC120  0 97753035  715  6619 1064347510KK140 40 4924-4132 7660 17A   1                  0    0    OGRSR2
1363  D2GHC041  KAM1205EXC120  0 97753036  733  6635 1063447510KK144 43 5517-4009 7314 16A   1                  0    0    OGRSR2
1364  D2GHC041  KAM1205EXC120  0 97753037  781  6676 1061047510VN125 90 5736-8192    0 10C Q 1                  0    0    OGRSR2
1365  D2GHC041  KAM1205EXC120  0 97753038  796  6687 1060247510JN340 75-9077 3304 2588 14B  1130                0    0    OGRSR2
1366  D2GHC041  KAM1205EXC120  0 97753039  803  6695 1059947510JN262 58 1180 8398 5297 15B   1   GV-9815  176 1908GRSR2
1367  D2GHC041  KAM1205EXC120  C 97753040  806  6698 1059747510JN   1 71-9454 -165 3256 22A   1                  0    0    OGRSR2
1368  D2GHC041  KAM1205EXC120  0 97753041  867  6751 1056747510SR 67 59-3349-7890 5150 19C Q 3                  0    0    OGRSR2
1369  D2GHC041  KAM1205EXC120  0 97753042  874  6757 1056347510JN321 88-7767 6289  349 11A   1                  0    0    OGRSR2
1370  D2GHC041  KAM1205EXC120  0 97753043  897  6777 1055247510JN 97 89 1218-9924  175 11A   1                  0    0    OGRSR2
1371  D2GHC041  KAM1205EXC120  0 97753044  911  6789 1054547510VN116 88 4381-8982  349 10C QT1                  0    0    OGRSR2
1372  D2GHC041  KAM1205EXC120  0 97753045  945  6818 1052847510VN155 85 9029-4210  872 12C QT1                  0    0    OGRSR2
1373  D2GHC041  KAM1205EXC120  0 97753046  958  6830 1052147510JN265 89  871 9960  175 12A   1                  0    0    OGRSR2
1374  D2GHC041  KAM1205EXC120  0 97753047  116  6100 1094247510SC312 82-6626 7359 1392 10CA                     0    0    OGRSR2
1375  D2GHC041  KAM1205EXC120  0 97753048  362  6314 1081947510SC138 90 7431-6691    0 11CA                     0    0    OGRSR2
1376  D2GHC041  KAM1205EXC120  0 97753049  585  6507 1070847510SC306 82-5821 8011 1392 10CA                     0    0    OGRSR2
1377  D2GHC041  KAM1205EXC120  0 97753050  610  6528 1069547510SC320 76-7433 6237 2419 11CA                     0    0    OGRSR2
1378  D2GHC041  KAM1205EXC120  0 97753051  760  6658 1062047510SC287 74-2810 9193 2756 11CA                     0    0    OGRSR2
1379  D2GHC041  KAM1205EXC120  0 97753052  847  6734 1057747510SC303 78-5327 8203 2079 10CA                     0    0    OGRSR2
1380  D2GHC041  KAM1205EXC120  0 97753053  977  6846 1051247510SC310 80-6330 7544 1736 10CA                     0    0    OGRSR2
```


Fig. 7. Part of the printout of file GH.CONV(3). Figures on the extreme-left are line numbers. For explanation see Table III.

Table III. Format of converted data records

Columns	Contents
1	'D'
2- 8	Traverse Identification (A)
9- 10	Domain (A)
11- 13	Formation (A)
14- 17	Mine Level
18- 20	Mine Location (A)
21- 23	Traverse Trend
24- 26	Traverse Plunge
27- 30	Traverse Length
31- 32	Number of Observations
33	Traverse Scale
34- 35	Sequences Number of Observations within Traverse
36- 39	Distance
40- 45	Easting
46- 51	Northing
52- 56	Elevation
57- 58	Type (A)
59- 61	Dip-direction
62- 64	Dip
65- 69	a
70- 74	b
75- 79	g
80- 82	Weight
83	Size (A)
84	Spacing (A)
85	Filling 1 (A)
86	Filling 2 (A)
87	Water (A)
88- 90	Waves
91- 92	Linetype (A)
93- 97	l
98-102	m
103-107	n
108-110	Lithology (A)
111-112	Hardness (A)

(A) denotes alphanumerica data; a,b,g are direction cosines for normals to planar structures; l,m,n are direction cosines for linear structures.

zero. 'Distance', 'Easting', 'Northing', and 'Elevation' are all in units of tenths of feet, the last three being relative to the Giant Mine's grid and datum. 'Dip-direction' is relative to True North.

C. RETRIEVALS

Retrievals from the data file built by CONVERT3 were accomplished using the program KEY4 (Ramsden, 1975). A general search and retrieval program for identical record data files, KEY4 identifies subsets of the data file, and the program is set up in such a way that it is possible either to save permanently the subset of record numbers produced by the operation, or to retrieve the data records and place them in a separate file. KEY4 allows a third choice: the data records may be both saved and retrieved.

The program scans the identical record data file (GH.CONV(3) in this survey) for the numbers of those data records satisfying a given condition. Possible conditions are defined by the relational operators: equal to, not equal to, less than, not less than, less than or equal to, greater than, not greater than, greater than or equal to, in the range, outside the range.

D. MANIPULATION AND DISPLAY

The data in file GH.CONV(3) are in a form suited to the production of density diagrams. Mathematical manipulation requires the data to be in the direction cosines of unit axes (or vectors if the facing direction is known); and whereas linear types *per se* can be regarded as unit axes (or vectors) and therefore without need of processing before manipulation,

planar types must be considered using their normals as unit axes. Polar density diagrams are the most common means of displaying structural data and these can be produced using the computer. However, corrections must be made for the effects of the non-random orientation of the traverse lines, for errors may arise from failure to take account of the orientation of traverses that lack sufficient variety to ensure a reliable estimate of the relative abundance of structural features.

In this study the orientations of the observed planar structures were recorded in terms of strike and dip relative to the traverse trend. However, a program converts these readings to dip-direction and dip, the normals of which are then considered as three-dimensional unit axes. Being non-polar, convention regards them as pointing downwards and they can therefore be regarded as unit vectors with a trend and plunge. Each unit vector is then considered in terms of three direction cosines which are given by the angles between the vectors and three mutually perpendicular axes (north, east and down). If T and P are considered as the trend and plunge of the unit vector, its direction cosines, a, b, g, can be represented by the following equations:

$$a = \cos T \cdot \cos P$$

$$b = \sin T \cdot \cos P$$

$$g = \sin P$$

$$a^2 + b^2 + g^2 = 1$$

A non-polar linear feature pointing downwards can in itself be regarded as a 3D unit vector, and its direction cosines are l, m and n. The same equations apply.

Ramsden (1975) has developed the concept of "keys", being files of line numbers that refer to subsets of data in a data file. Keys eliminate the necessity of scanning an entire data file when only subsets of data are required. This tool proves very useful when keys are repeatedly handled, and where any one subset of data is used in several different ways; it can be used in more than one key. The major keys used in the manipulation of the GH.CONV(3) data are listed in Table IV.

Further keys were generated by forming all possible combinations between levels and longitudinal division, and between these and the various structures.

The structural data are counted on the reference sphere and the densities printed out on the equatorial plane in an equal area projection. The orientation diagrams of spherical point distributions are based on the fact that the radius of the unit sphere, a unit vector, cuts the unit sphere at one point, so that a cluster of vectors gives rise to a polar distribution. Also a cluster of axes, i.e., diameters of the unit sphere, gives rise to a bipolar distribution. Axes scattered about a plane give a girdle distribution. Axes or vectors with no preferred orientation give rise to a uniform distribution (Ramsden, 1975).

Ramsden's (1975) program MODEL1 computes certain vector and axis statistics and implements various probability tests. The program WNDPLOT3 (Ramsden, 1975) uses this output to produce equal-area projections of the spherical distribution of points. WNDPLOT3 operates by estimating the density of points within a predetermined counting circle at each of a number of predetermined counting locations. There are 2933 counting locations which are defined by direction cosines read in by the

Table IV. Major keys used in the manipulation of the file GH.CONV(3)

"Regions"	0950LEV 1100LEV 1250LEV 1500LEV	representing the four levels of the mine in the study
	WEST CENTRAL EAST	arbitrary longitudinal division at local mine grid eastings 250E and 500E
"Structures"	JOINTS FAULTS VEINS	the three predominant surface types
	FIBRES GROOVES CRINKLE	the three predominant linear types
	LINEARS	all the line types combined

program at the start of each run (Ramsden, 1975). After the counting procedure is completed, the program constructs the plot, line by line, and the appropriate character is printed. The printed character represents the percentage of the data sample counted in the counting circle, and also represents the estimate of the density of a uniform distribution of all the points.

Account must be taken of the angle of intersection between the observed structures and the traverse line. The convention used is one devised by Terzaghi (1965). She considered the cases for vertical drill holes and horizontal rock outcrops, but the same theory can be applied to horizontal line traverses. The number of, say, joints intersected by a traverse line is given by:

$$N_\alpha = \frac{L\sin\alpha}{d}$$

where N_α is the number of joints; L, the length of the traverse; α, the angle of intersection; and d, the spacing between the joints.

"If the investigator must rely on observations from [straight line traverses] with a nearly uniform orientation, joint orientation data are unlikely to provide even approximately correct information concerning the abundance of joints of all sets present in the locality" (Terzaghi, 1965, p. 295).

Density diagrams were produced (a) with no correction factor, (b) with an arbitrary correction factor of 5, and (c) with a maximum correction factor of about 11.5. Such high correction factors are, however, intuitively regarded with some suspicion. Of concern is the fact that many of the traverses are subparallel to the major shear zone structures. Another point that must be considered is that there are no vertical traverses. Terzaghi's warning must be borne in mind when comparing diagrams!

Chapter VI

DATA DESCRIPTION

The structural data were first analysed by comparing stereograms developed for each of the 14 major keys (see Table IV). Note that in the descriptions below the surface and linear types are described in turn by level (representing the four levels of the mine in the study) by longitude (arbitrary division at the mine grid eastings of 250E and 500E - hence East, Central and West), and by level and longitude together.

A. JOINTS

1. By Level

All stereograms show a broad spread of poles along the primitive circle indicating predominantly vertical or nearly vertical joints that strike between due north and about N45° (fig. 8). Most stereograms display one concentration of poles that indicate near vertical joints having a dip-direction of about N290°. Secondary maxima suggest a joint set dipping very steeply to the ESE. Most stereograms also indicate a weak, nearly horizontal joint set - notably absent from the 1100 Level.

2. By Longitude

A fairly simple pattern on the lines described above exists for joints in the East and West (fig. 9A,C). The stereograms show a broad maximum of poles for near vertical joints with dip-direction N290-310° and the possibility of a horizontal set in the east. However, a slightly different pattern of poles is displayed by the stereograms for Central joints (fig. 9B): there is a broad discontinuous girdle of poles

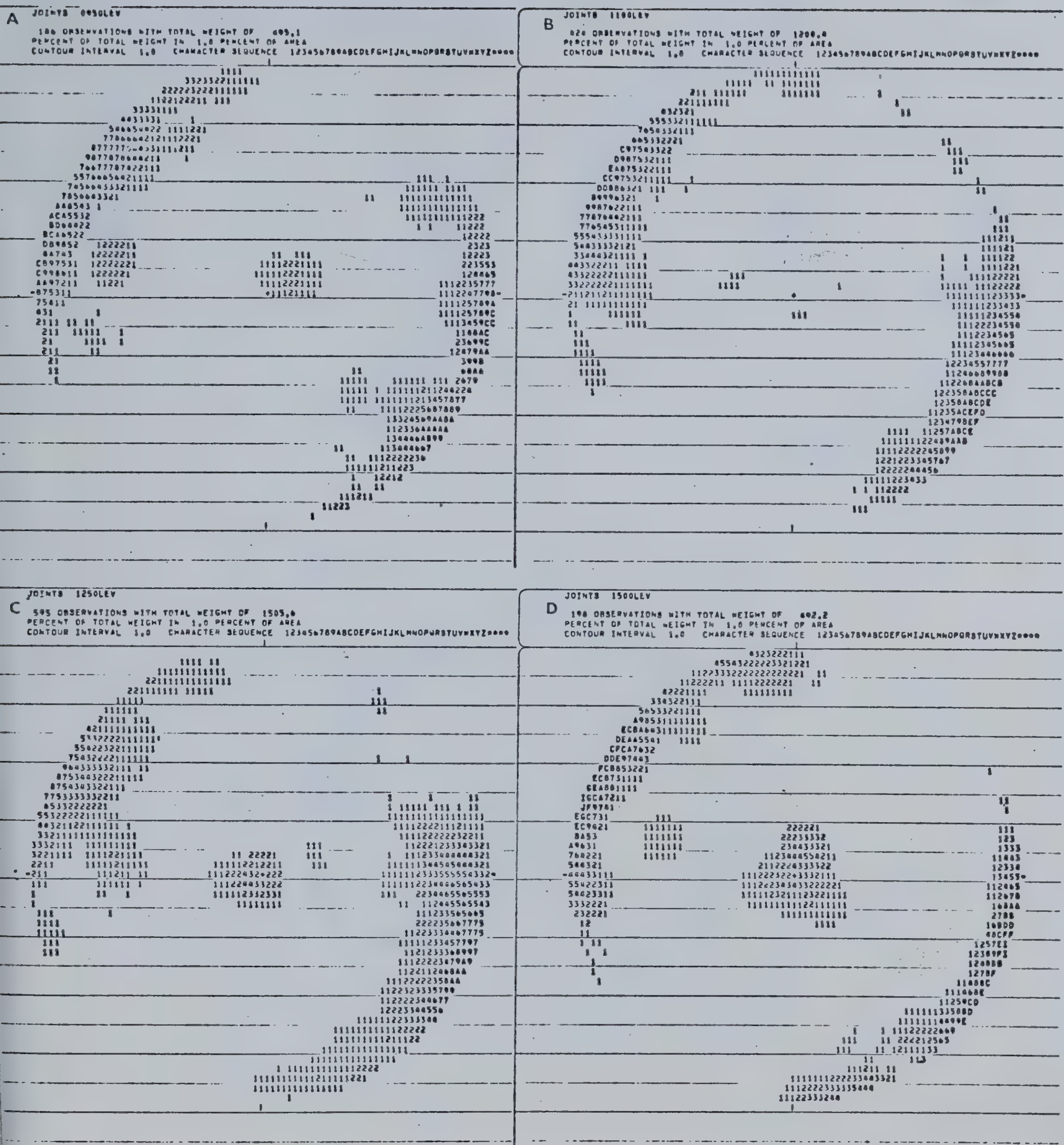


Fig. 8. Poles to joints.

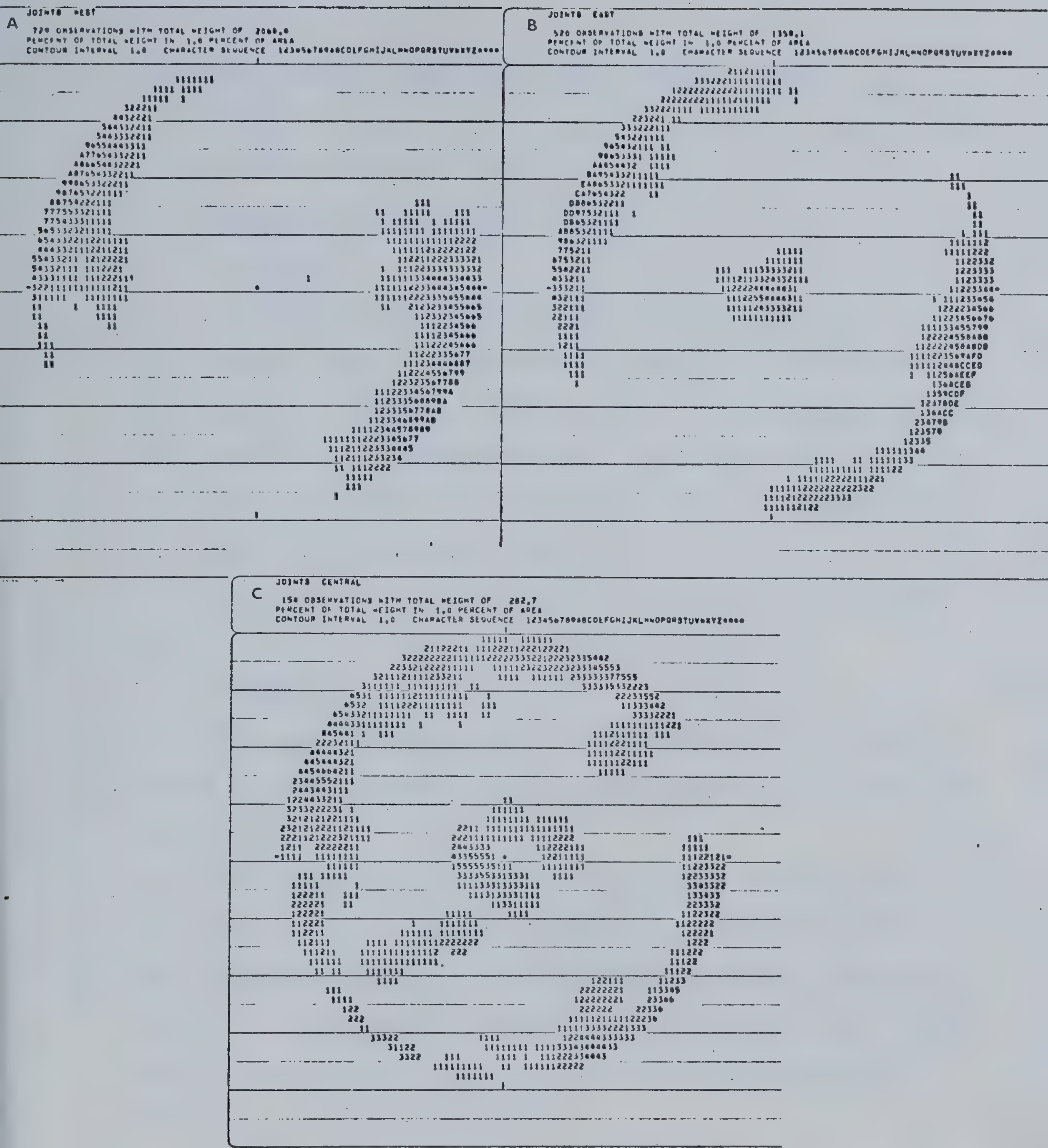


Fig. 9. Poles to joints.

around the primitive circle with three low maxima indicating near vertical joints with dip-direction between N275° and N330°. There is also a suggestion of horizontal joints.

3. By Level and Longitude (figs. 10 and 11)

(a) 0950LEV.

(i) West (186 observations). The stereogram (fig. 10A) shows a fair spread of poles; about 60% indicate near vertical joints with a dip-direction about N100°, and 30% show a second, approximately vertical joint set with a dip-direction of N310°. A possible third joint set (less than 5%) dips steeply SE, dip-direction being about N160°. There is a suggestion of a horizontal joint set.

Only the western horizontal division is represented on the 0950 Level.

(b) 1100LEV.

(i) West (303 observations). A broad maximum of poles (90%) indicates a steeply NW-dipping joint set with dip-direction of about N300° (see fig. 10B).

(ii) Central (49 observations). The pattern of poles in the stereogram (fig. 10C) indicates a girdle about the primitive circle. There are, however, numerous low maxima (mostly less than 20%) around the girdle. One near vertical joint set (about 25%) has a dip-direction N314°. Another set (also about 25%) dips 87° to N207°. There is no indication of a horizontal joint set.

(iii) East (72 observations). A discontinuous girdle is indicated for the data (fig. 10D), but a prominent maximum (45%) shows a joint set dipping 85° to N295°. A near vertical joint set with a maximum of 40% has a dip-direction of N250°, and another dips about 30° to N95°.

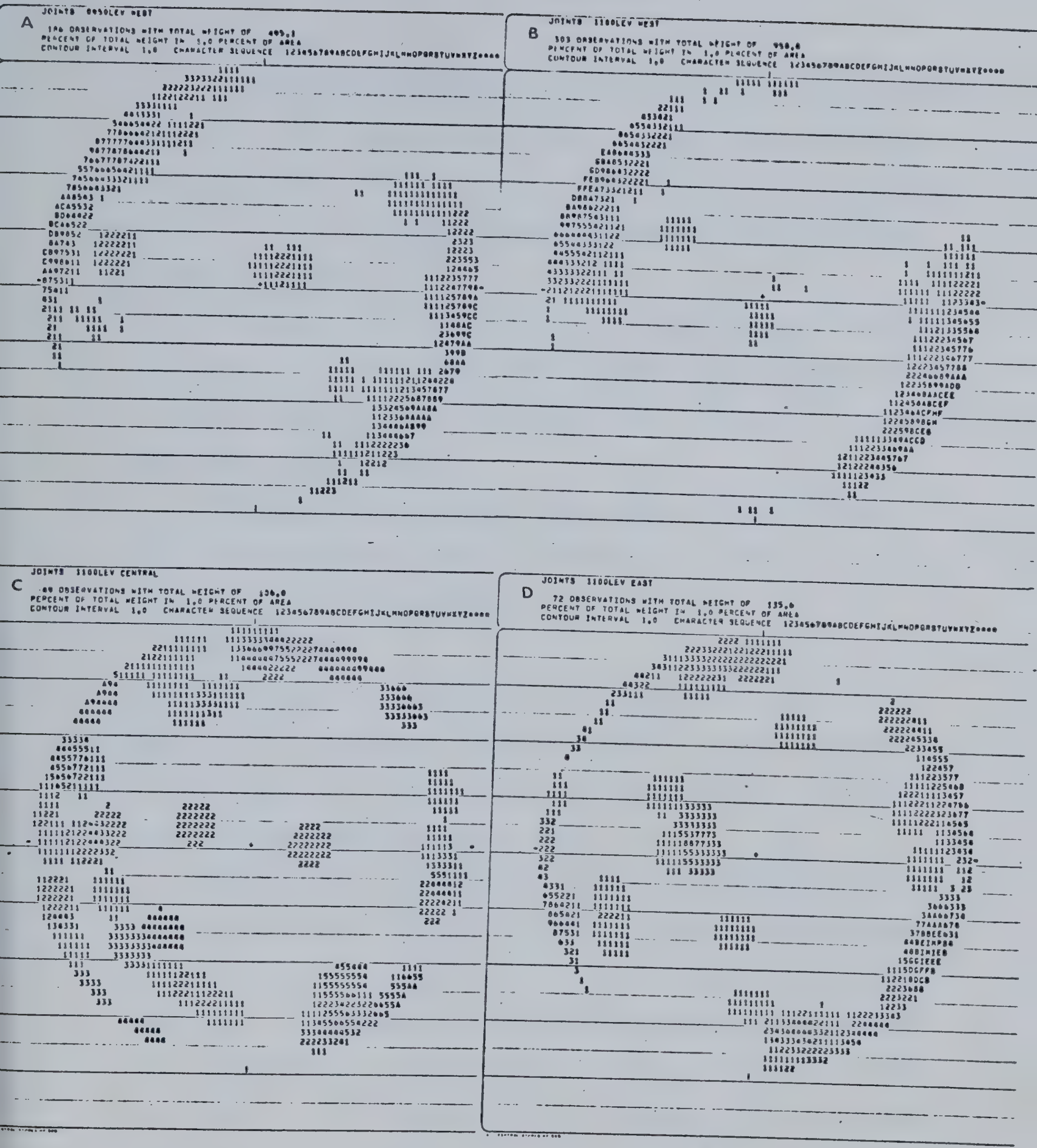


Fig. 10. Poles to joints

(c) 1250LEV.

(i) West (240 observations). No horizontal joints are indicated (fig. 11A). One cluster of poles (40%) indicates a set of joints dipping 78° to N268°. The second maximum (40%) indicates a joint set dipping 80° to N310°. A third maximum (10%) suggests another joint set dipping 64° to N95°.

(ii) Central (105 observations). An unclear pattern is shown by the diagram (fig. 11B). Noteworthy is a maximum of poles (10%) showing a joint set dipping only 15° to the NE. Other near vertical joint sets dip steeply to the SE and NW.

(iii) East (250 observations). The diagram (fig. 11C) shows a polar maximum (60%) for a joint set dipping 88° to N295°. A horizontal joint set (15%) is also apparent.

(d) 1500LEV.

(i) East (198 observations). 70% of the poles indicate a near vertical set of joints with dip-direction N108°. A nearly horizontal set (20%) dips 10° to N197°. Another vertical joint set, dip-direction N165°, is also indicated (see fig. 11D).

Table V displays the orientations of the more important joint sets for each subdivision. In all three divisions, West, Central and East, there is a steeply northwest-dipping joint set with a dip-direction of N295-315°. In the West and East divisions another possible joint set has a dip-direction of about N95-110° but with a rather more variable dip (30-89°). In the Central division a joint set dips steeply southwest. There is a suggestion of a joint set with dip-direction N250-270° on the 1250 Level West and the 1100 Level East. An approximately horizontal joint set is found more or less throughout the study area. In

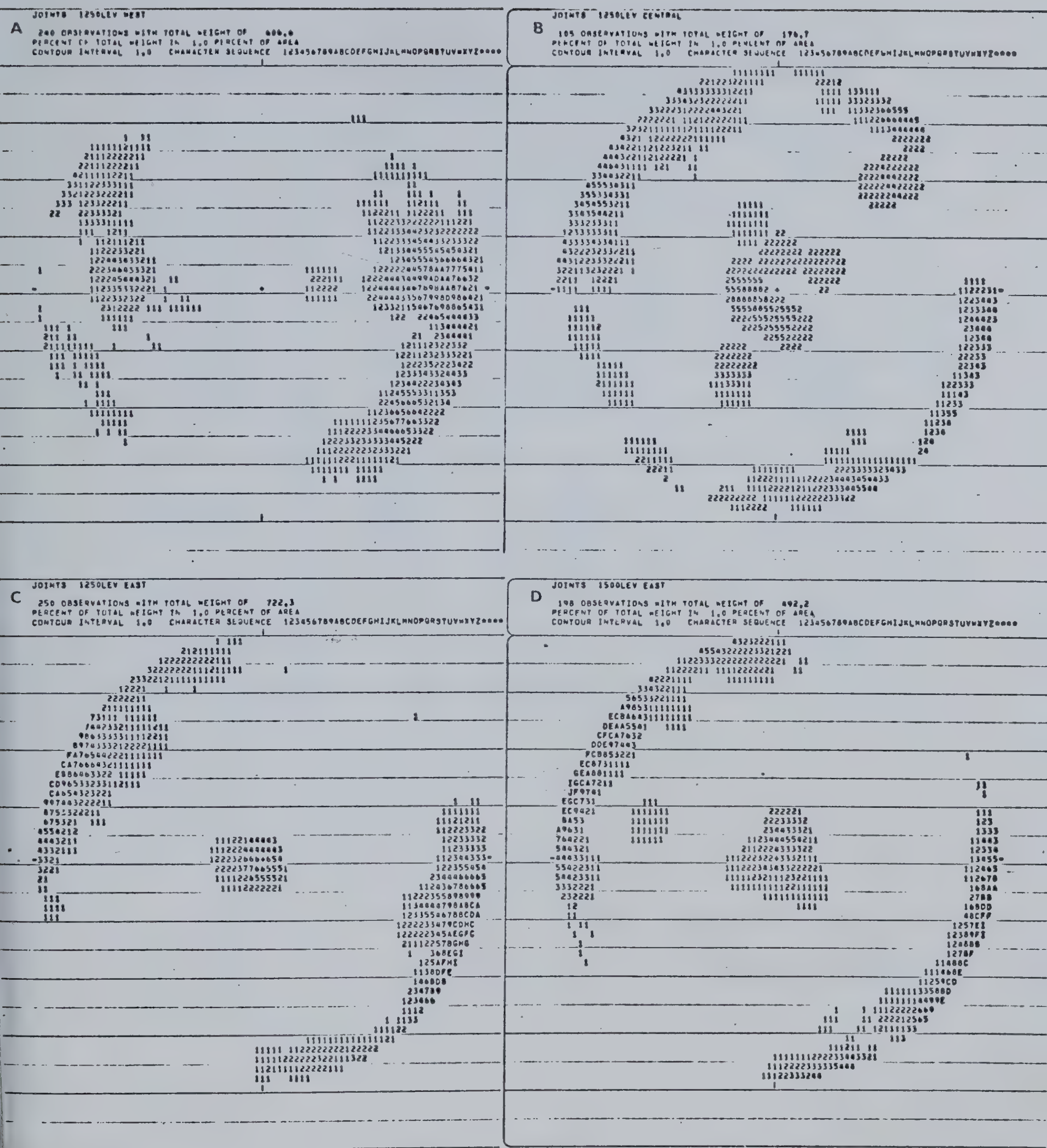


Fig. 11. Poles to joints.

Table V. The orientations (dip-direction/dip) of the more important joint sets

	West	Central	East
0950 LEVEL	100/88 310/88 horizontal		
1100 LEVEL	300/88	(girdle) 315/88 205/87	(discontinuous girdle) 295/85 250/88 95/30
1250 LEVEL	270/78 310/80 95/64	30/15 125/85 215/87	295/88 horizontal
1500 LEVEL			110/89 200/10 165/89

the Central division, and to a lesser extent in the East, several other joint sets are apparent.

The predominant joint set that dips steeply to the northwest reflects the attitude of the schistosity in this part of the mine. The slight differences from West to East may or may not be significant. Previous studies (e.g., Boyle, 1955; Brown, et al., 1958) also noted a slight change in orientation across the shear zone. However, the relationship between schistosity and the Giant Mine ore-bodies, which tend to plunge northwards, is not clear. Moderately east-dipping joints are encountered in the Con Mine at Yellowknife (Z.T. Nikic, personal communication, 1975). These may be related to the nearly horizontal joint set in Giant Mine and could conceivably be a result of pressure release associated with erosion of overlying rocks.

In this part of the Giant Mine the shear zone dips vertically or steeply eastwards yet the schistosity dips vertically or steeply west. This appears to be indicative of shearing whereby the eastern side moved upward relative to the western side.

B. FAULTS

Several sets of faults are evident and none of them appear to be restricted to any one part of the study area. Although only 54 observations of faults were made, and the breakdown into longitudinal divisions and levels lessens the control on the fault data, the following observations tend to hold for most stereograms.

There are two dominant fault orientations (see fig. 3B). One series of faults has a near vertical dip and a dip-direction of N320-345°

(60%). A second set of very steeply dipping faults (20%) dips westwards (N275-280°). Together these two groups of faults comprise a conjugate fault set, roughly 65° apart, bisected by the shear zone schistosity.

Also, there are several faults (10%) with moderately steep dips (50-80°) and a dip-direction between N235° and N300°, and others that dip towards the southeast (<10%).

C. VEINS

There are 234 observations on veins. Note that the stereograms do not distinguish between quartz, carbonate and quartz-carbonate veins.

The stereogram for all veins (fig. 3C) shows a non-random pattern in which veins that dip moderately to the southwest or west and veins that dip steeply east and north are most common. There is also a suggestion that there is a set of nearly horizontal veins. Two vaguely defined girdles are apparent containing the poles to the veins. [One girdle dips shallowly to the east (about N90/20), the other rather more steeply to the south-southwest (about N195/70). The girdles are approximately 75° apart in a steeply northwesterly dipping plane (about N290/70).].

On breaking the data down into levels and longitudinal divisions, at least three sets of veins are evident. Table VI gives the orientations of these and the other more important sets of veins for each subdivision.

One set, with an orientation of about N240/76, is important in the West division (0950LEV West, 1250LEV West; see fig. 12A). Another set dips very steeply eastwards (N90/84) and is apparent to a certain degree throughout the area on all levels (fig. 3C). A third set of veins that dips steeply southwards (N175-195/80-90°) appears to be absent from the

Table VI. The orientations (dip-direction/dip) of the more important sets of veins

	West	Central	East
0950 LEVEL	180/90 240/87 330/72 85/86	...	
1100 LEVEL	40/12 355/46	290/89	90/88
1250 LEVEL	15/90 240/65 305/76 330/76	135/79 100/89	215/75 175/83 200/79 115/88
1500 LEVEL			85/71 75/54 25/45

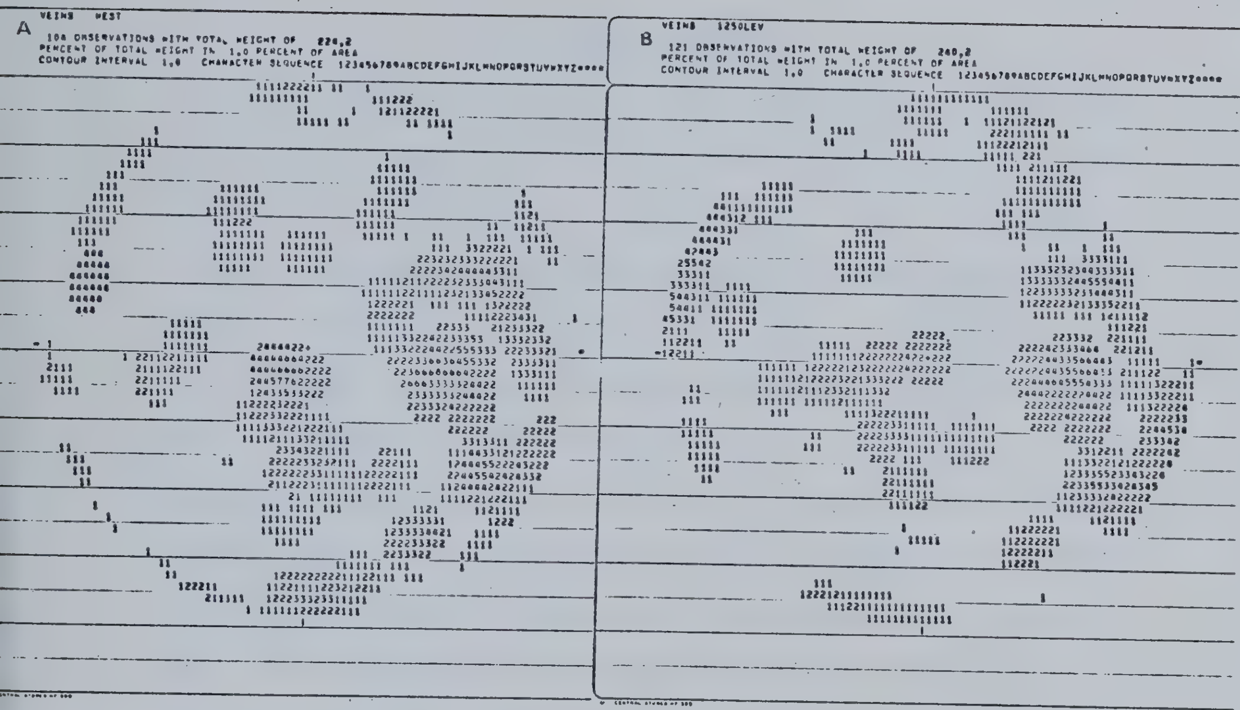

A
VEINS WEST
PERCENT OF TOTAL WEIGHT IN 1.0 PERCENT OF AREA
CONTOUR INTERVAL 1.0
B
VEINS 1250LEV
121 OBSERVATIONS WITH TOTAL WEIGHT OF 240.2
PERCENT OF TOTAL WEIGHT IN 1.0 PERCENT OF AREA
CONTOUR INTERVAL 1.0

Fig. 12. Veins.

Central division but only 26 observations fall into this group. Horizontal veins are not locally prominent. Moderately northwest-dipping veins are most common on the 0950 and 1250 Levels (fig. 12B).

D. LINEAR STRUCTURES

Three linear structures were observed and measured on fault and joint surfaces. One was a crinkle lineation, but as only three observations of this were made its significance will not be considered further. Twenty-five observations of grooved slickensides, GROOVES, and 184 observations of fibrous mineral growths, FIBRES, were made.

The stereogram (fig. 13A) which combinates all the linear structural information, LINEARS, indicates a nearly north-south girdle of points about an approximately horizontal axis which trends N95-100°. However, within this girdle several maxima are apparent that indicate linear structures which plunge either very steeply or at a shallow angle. The following are the trends and plunges, respectively, of the four most prominent clusters of points: N10-10°; N20-75°; N180-70°; N185-20° (90% of total). Most, but not all, other stereograms of subsets of these data agree fairly well with this pattern. The stereogram for FIBRES (fig. 13B), for instance, is almost identical, and a strong girdle array is evident, but other stereograms show moderately and gently plunging linears plunging to the northeast and southwest.

E. FIBRES

1. By Level

The stereogram for the 0950 Level (40 observations) does not show

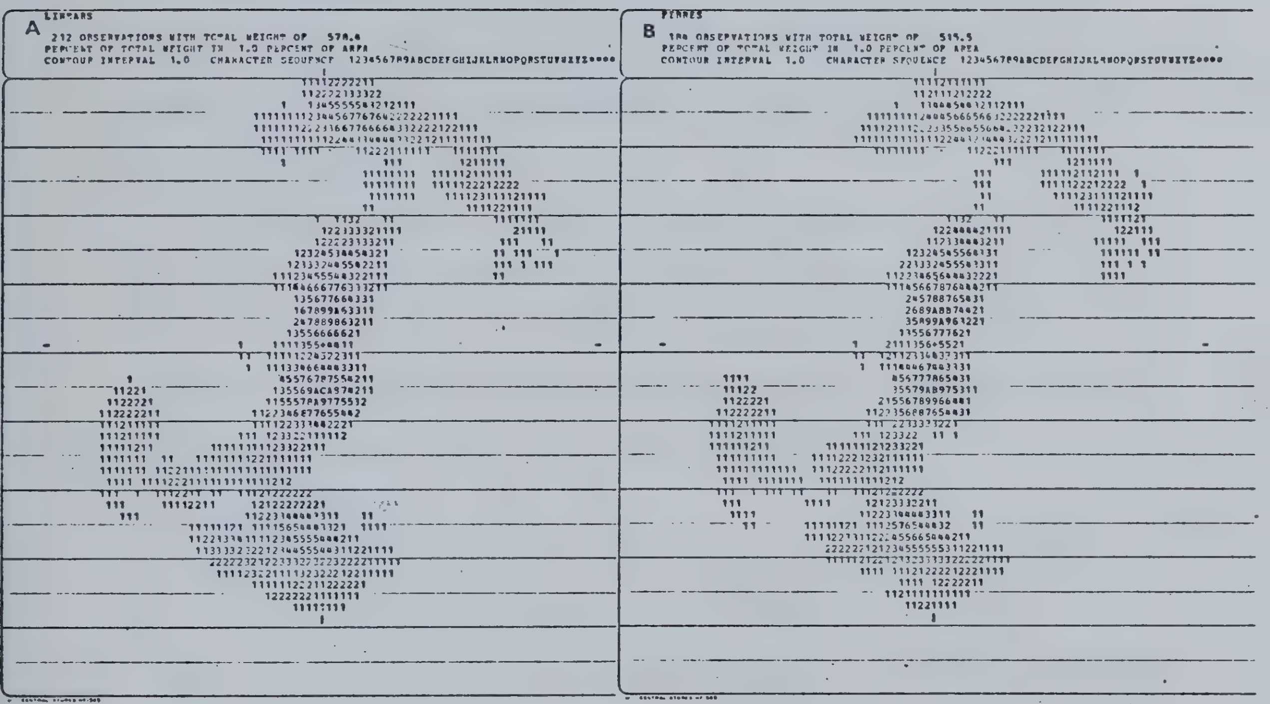


Fig. 13. Linears; fibres.

a girdle, though the clusters of poles are identical to three of those noted above (90% total).

A roughly N-S girdle is displayed by the stereograms for both the 1100 and 1250 Levels (fig. 14A). In each case the axis for the girdles is approximately horizontal and trends about N95°. Although there is some evidence of minor, shallowly NE and SW plunging fibres on the 1250 Level, steeply north and south plunging fibres are dominant (over 60% on the 1100 Level).

The girdle pattern in the stereogram for the 1500 Level (28 observations) is somewhat fragmented but still quite obvious. The shallow NE and SW dipping fibres are also in evidence and hint at a second girdle about a horizontal axis that trends southeast. Again, steeply north and south plunging fibres are dominant (45% together).

2. By Longitude

With more than half of the observations occurring in the West division (104 observations on fibres), the stereogram, FIBRES WEST, shows a good girdle pattern developed about a horizontal axis trending approximately N95° (fig. 14B). Also obvious are the four structural orientations noted above (over 90%) - with fibres plunging steeply and shallowly to the north (N5-75°; N10-10°) and the south (N185-70°; N185-20°). There is little evidence of a second girdle.

A similar situation exists in the East where the stereogram, FIBRES EAST, indicates a fairly good N-S girdle about a horizontal axis (fig. 14C). The shallow, south plunging fibre cluster is absent and there is some suggestion of shallow NE and SW plunging fibres.

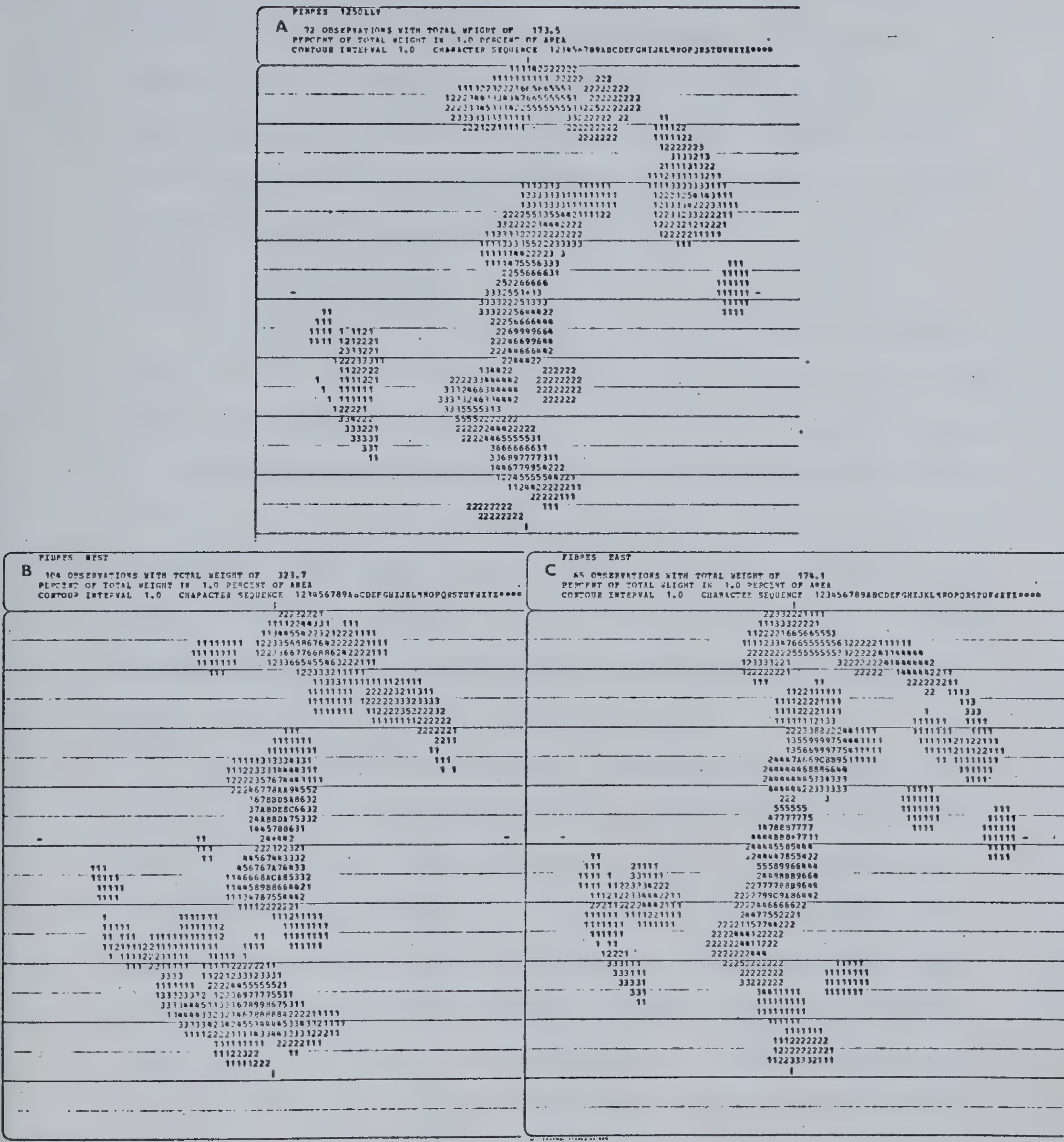


Fig. 14. Fibres.

In the Central division the situation is not clear. The stereogram, FIBRES CENTRAL, involves only fifteen observations. The N-S girdle is absent. There is a rough northeast-southwest girdle about a horizontal axis trending about N150°. Two polar maxima indicate fibres plunging shallowly to the southwest and northeast (N245-10°; N65-20°), but there is a third maximum showing fibres plunging N150-10°.

3. By Level and Division

No changes in orientation of fibres are discerned by breaking the data down into level and division. Stereograms for 0950LEV West, 1100LEV West, 1250LEV West, 1250LEV East and 1500LEV East all display to a greater or lesser degree the north-south girdle, and have the four polar maxima of fibres plunging steeply and gently to the north and south. Both 1250LEV East and 1500LEV East also suggest a NE-SW trending girdle, and this is the pattern produced by fibres for the 1250LEV Central stereogram where the N-S girdle is absent. (The 1100LEV Central and 1100LEV East have too few observations for worthwhile comment.)

Fibrous lineations are plotted on stereographic projections as two girdle patterns, one of which is dominant. Both girdles are developed about horizontal axes a little under 60° apart in the horizontal plane. The horizontal angle between the two girdles is bisected by the schistosity. The attitude in space of the girdles is identical to the conjugate fault set described in a previous section. This suggests that because most of the linear data were observed on "joints" the joints are in fact "mini-faults", and that these faults and joints were developed during a dilatant stage allowing fibrous mineral growth. The direction of mineral elongation was, of course, a response to the prevailing stress

field. The clusters of fibrous lineations within the girdles indicate that the stress field changed. Whereas the gently plunging fibres in both girdles indicate that approximately horizontal shearing took place, the steeply plunging fibres suggest some vertical movement along the faults - perhaps at a later, and still dilatant, stage. The maxima for vertical fibres appear to be associated only with the N-S girdle. Vertical movement was therefore confined to the N-S trending faults.

F. GROOVES

There are only 25 observations on grooves. Most stereograms of subsets of the data therefore do not contain enough information to allow comment. This is especially true of the stereograms for data subsets of longitudinal divisions and levels. By level, only the 1250 Level stereogram (14 observations) shows an appreciable pattern. There is a vague suggestion of a north-south girdle in which a cluster of poles indicates steeply south plunging grooves. A nearly identical pattern is displayed by the stereogram, GROOVES EAST (13 observations), which, in addition, suggests gently north plunging grooves. Both contain poles of moderately southwest plunging grooves.

The pattern of grooves does not disprove in any way the ideas expressed regarding fibres. Rather, the pattern of grooves supplements the pattern of fibrous lineations. For though dilatant conditions prevailed over most of the area at the time the faults and joints ('minifaults') were being formed, locally the respective fault blocks impinged and rubbed against each other thereby causing grooved slickensides to form.

It is likely that the schistosity preceded such fault and joint development, and it is possible it had an influence on the orientation of the later structures.

Chapter VII

MICROSTRUCTURES

A. INTRODUCTION

Forty-two thin sections were made from the orientated samples collected on the four levels of the study area. A further seventy-seven thin sections had been made from a 150-foot long diamond drill core from a hole drilled completely across the main Giant shear zone, but somewhat above the study area.

A number of thin sections were stained in order to distinguish between carbonate minerals. A combined organic and inorganic stain was used. The solution, developed by Evamy (1963 - see also Friedman, 1971) includes alizarine red S, potassium ferricyanide and hydrochloric acid. The thin sections did not need prior etching and the stain was applied directly to produce the following colours: iron-free calcite - red; iron-poor to iron-rich calcite - mauve to purple; dolomite (*sensu stricto* i.e., iron-free) - unstained; iron-poor dolomite to iron-rich dolomite and ankerite - light blue to dark blue.

B. OBSERVATIONS

Immediately apparent is a schistosity that is either cut or paralled by several sets of veinlets. The schistosity is naturally most strongly developed at the centre of the shear zones.

A relatively unsheared fine-grained greenstone groundmass passes from a mafic chloritic rock, locally with the remains of amphiboles, into strongly schistose sericite-chlorite and sericite-carbonate rocks.

Quartz and carbonate minerals, either mobilized *in situ* or introduced from elsewhere, occupy much of the central parts of the schist zones where shearing has been most intense.

Small faults with a displacement up to 5 mm are common parallel to the schistosity in the central parts of the shear zones. Iron-rich carbonate and quartz-carbonate veins tend to parallel and emphasize the overall foliation and are often bounded on one side by one of the small faults mentioned above. The veins were initiated during the formation of the shear zones, and movement locally appears to have continued after vein emplacement.

Shearing, and the presence of various veins, commonly impart a banded nature to the schists. Typical alternating bands might be of chlorite schist, quartz-carbonate-sericite schist and relatively coarsely crystalline carbonate veins. Fine-grained sericite occurs where shearing appears to have been most intense. Strings of opaque sulphides and leucoxene in places add to the banded appearance.

Not uncommon in some of the shear zones is a breccia-like feature that may or may not have a real tectonic origin. A few thin sections from the study area display patches of fine-grained quartz, strained coarse-grained quartz, and sericite, separated by thin sericitic and chloritic shear zones. These often carry finely comminuted opaque minerals including leucoxene and sulphides. Quartz and sericite pressure fringes are common around some of the opaque minerals. However, thin sections taken from the core show all manner of textural variations, and the irregular aspect might be due to the section having been cut approximately parallel to the schistosity so that undulations in the

schistosity give rise to spindle-shaped "fishes" of more competent rock within a sea of sericite and chlorite.

A crinkle undulation in the schistosity has in fact locally given rise to bands of darker and lighter green-coloured chlorite. This feature is seen only in the thin sections cut normal to the schistosity. Poorly developed and vague kink bands are seen in one thin section.

Fold structures are, however, not particularly common. Folding is generally restricted to drag-type structures adjacent to the shears. The small drag folds with an amplitude up to about 2 mm are commonly outlined by thin layers of opaque minerals. Crosscutting veinlets are deformed into folds whose axial surfaces parallel the schistosity, and although these veinlets are very thin, they are nevertheless persistent within the area of the thin section.

A few thin sections, both normal and parallel to the major foliation, contain small (0.5 mm long) tabular andesine (?) plagioclase crystals at odds with the dominant schistosity. There is a suggestion the crystal laths describe a conjugate set 60° apart, that may or may not be bisected by the schistosity. The grains do not seem to lie in a single plane perpendicular to the foliation.

Unlike the feldspars of the groundmass these grains are not obscured by extensive sericitization. The grains are strained and they show mainly simple twinning: repeated twinning with fine lamellae is absent. Gorai (1951) and Turner (1951) agreed that plagioclase twins are rare in metamorphic rocks; that if they are present they tend to be simple rather than multiple twins; and that there is a tendency for the twins to be albite or pericline and not conform to the other laws.

Turner also noted that "there seems to be no general correlation between abundance of twinning in metamorphic plagioclase and degree of deformation experienced by the enclosing rock" (Turner, 1951, p. 582). The presence of these relatively unaltered feldspars in schistose rocks characterized by extensive alteration indicates that there must have been a late thermal event after the main period of shearing and sericitization. Also the strained nature of the grains and their orientation with respect to the dominant foliation point to a late shearing event.

Nine thin sections from along the core were initially chosen for staining. Distinct, clear colours revealed at least four carbonate minerals in the rocks, namely: iron-free and iron-rich calcite, and dolomite and ankerite. It is not known how the stain affects other carbonate minerals such as siderite. The stained thin sections showed an increase in the iron content of the carbonate minerals of the veins towards the central parts of the shear zone. Fifteen thin sections from the study area were also stained. These were chosen mostly from within the main part of the major shear zone, or from nearby. The results supported the first observations: that there are several carbonate minerals in these rocks and that the vein carbonates become markedly more iron-rich towards the central parts of the shear zone.

In any one thin section from a locality away from the shear zone the occurrence of small specks and blotches of iron-free calcite is a common feature. There may or may not be a minor amount of iron-rich calcite. Ankerite becomes increasingly important in the groundmass near the centre of the shear zone. Intensely sheared rock has ankerite as the predominant groundmass carbonate, with minor amounts of iron-free

calcite being present locally. Iron-free calcite is the most common vein carbonate. Ferroan calcite or ankerite may be present in small amounts in some veins. In the central parts of the shear zones there are uncommon veins of iron-poor calcite and dolomite, and in places these veins can be seen cutting across the ankerite-rich groundmass, the calcite and the dolomite replacing the ankerite (see Plate A). Not yet observed is the presence, together, of three different carbonate minerals that crystallized at the same time.

Concomitant with the increase in iron content of the carbonates as the shear zone is approached is the replacement of chlorite by sericite. It is possible, therefore, that during shearing and the chlorite to sericite alteration iron was mobilized, and was taken up by the vein carbonates. There also appears to be a change in the epidote minerals. In the central parts of the shear zones epidote may locally give up some iron: clinozoisite has been identified with some uncertainty.

With regard to the relationships between microstructures, the assumption has to be made that the all pervasive schistosity seen in the thin sections was due everywhere to the major shearing event that formed the shear zones. It can be argued that another shearing event may have occurred locally before or after the major event. If the major shearing did not affect all rocks everywhere there may be evidence of a former, less important, schistosity. Alternatively, later shearing after the major event could locally obscure the earlier schistosity.

Assuming there was but one major schist-producing event, the following observations can be made. Vague to locally well defined bands of chlorite and minor amounts of other minerals are cut by the schist-

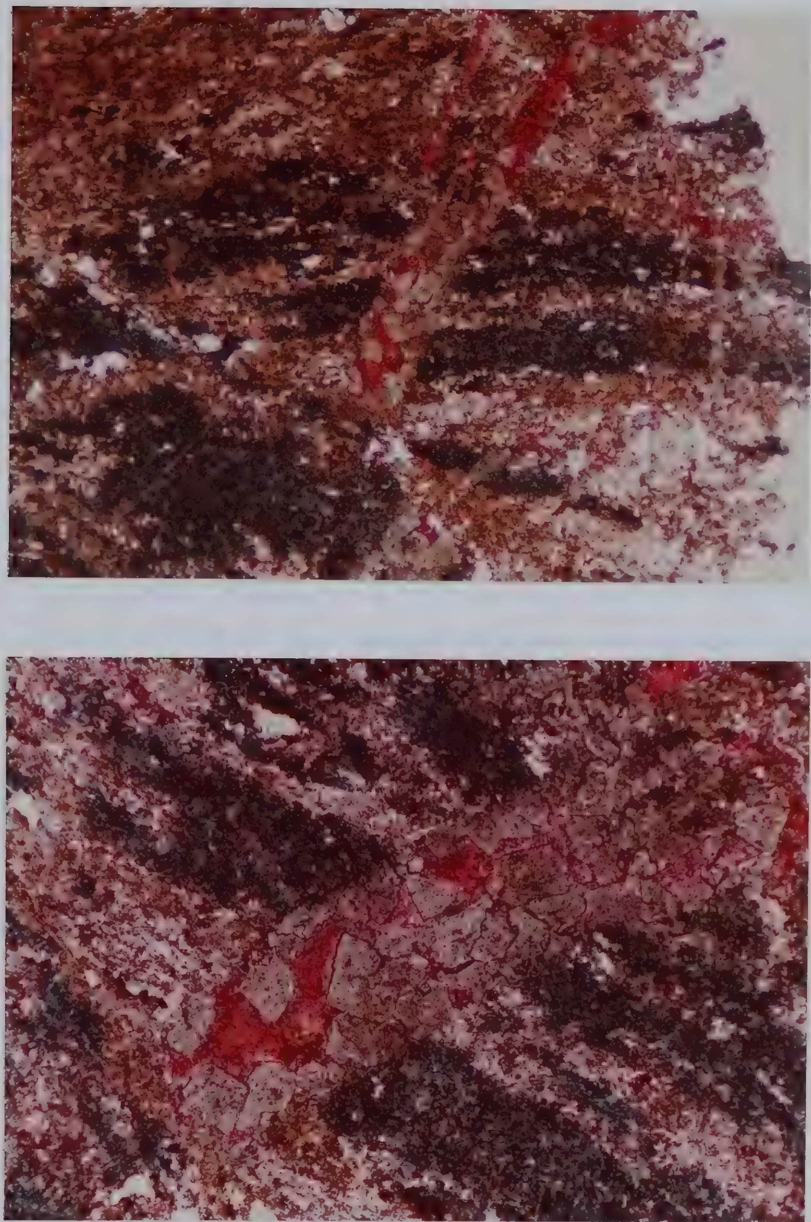


Plate A. Photographs of a stained thin section in plane polarized light. Vein of iron-free calcite (red) and dolomite (unstained) cutting across chlorite-sericite groundmass containing ankerite (blue). Vein is about 0.3 mm wide.

osity. These bands are interpreted as possibly being the remains of altered pillow margins. Some quartz-calcite-ankerite veinlets were emplaced prior to shearing. Where deformation was not particularly intense they can be seen to have suffered folding or rotation, and displacement parallel to the schistosity. They have been obliterated from the central parts of the shear zones. Numerous quartz and quartz-carbonate veins, pods and rodded masses were emplaced parallel to the schistosity. Some of these may originally have been discordant to the schistosity but during deformation have become rotated parallel or nearly parallel to the schistosity. There are several sets of quartz and carbonate veins discordant to the schistosity that were emplaced after the major shearing event. Most of the strictly quartz veins cut across the schistosity at about 90°. The quartz-carbonate and carbonate veins tend to comprise a group that trends anywhere between 20 and 45° to the schistosity. Although there are exceptions to the rule, where relations are seen, the carbonate veins are commonly younger than the quartz veins. Locally, the quartz-carbonate veins comprise a central calcite section bordered by quartz. Ubiquitous narrow shear zones, at odds with the schistosity, give evidence of minor deformation after the major event. Most of these minor shears are post-vein development but some show relations that indicate vein emplacement was contemporaneous or later than the minor shears. These minor secondary shears appear to have all conceivable orientations. However, relative to the major schistosity, there is a tendency for them to be orientated at about 20-25° and 135-155°.

Chapter VIII

STRUCTURAL ANALYSIS

A. INTRODUCTION

One major structural problem at the Giant Mine is to account for the apparent folded character of the shear zones. Fig. 15 shows the general nature of the "antiform-synform" pair formed by the zones. Schist development within the zones provides evidence of ductile deformation along them, and there are indications of folding within the zones which Brown, et al. (1959) ascribed to "drag".

Between sections 1500'S and 2500'N (about 1300 m) the crest of the western antiform plunges northward at 15-25°; the trough of the central synform and the crest of the eastern antiform both plunge south at an average angle of 12° (Brown, et al., 1959). Brown, et al. (1959) noted that the amplitude of the antiform-synform pair changes from about 1600 ft (500 m) near the 'C' Shaft to less than 600 ft (180 m) some 4000 ft (1200 m) northwards.

A regional folding hypothesis was advanced during the early exploration work to account for the attitude of the shear zones. Geologists thought that the shear zone might be confined to a tuff bed caught up in regional folding. However, detailed mapping of the Yellowknife greenstone belt by Henderson and Brown (1952) indicated that the greenstones were unfolded, and it was concluded that the Giant and Campbell shear zone systems followed major early faults (cf. Bateman, 1952). Brown and Dadson (1953) and Brown, et al. (1959) attempted to apply stress and strain analysis to the problem to explain the zone origin by shearing, but to the

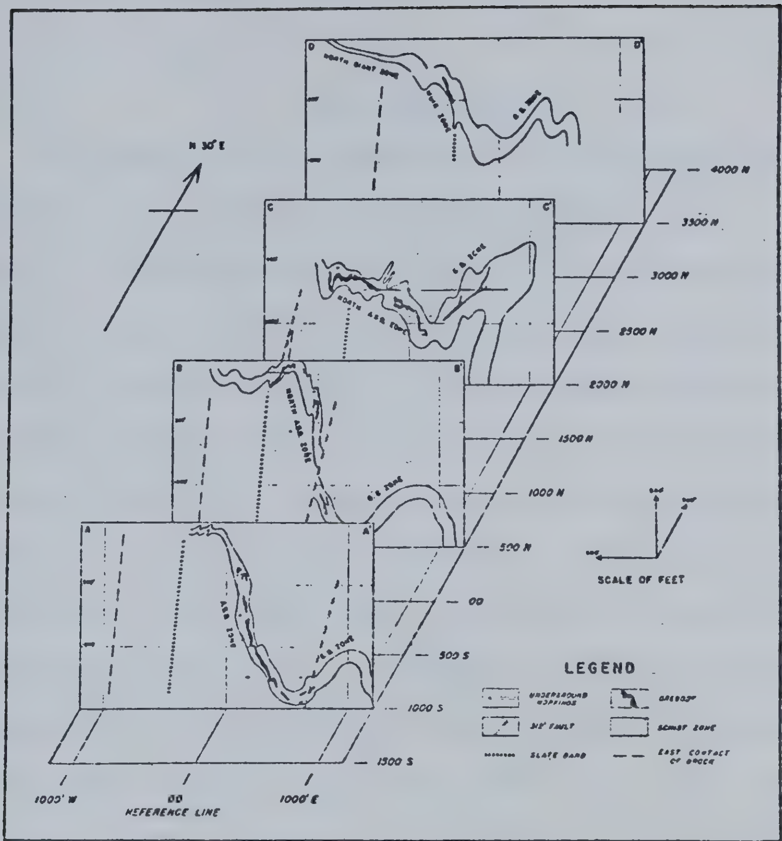


Fig. 15. Isometric drawing of part of Giant Mine. Study area lies near trough of synform immediately north and south of section A-A' (after Brown, et al., 1959).

present day the geological staff at Giant have "no firm concensus" regarding the structure there (B.F. Watson, written communication, 1976).

B. STRAIN ANALYSIS

Measurements of the geometrical effects of displacement and internal distortion can be made with a view to estimating the nature and amount of strain. Where large-scale rock deformation has taken place by ductile flow it is usual to find that the finite strain state varies from place to place. Where high strain states in deformed rocks have been localized in roughly planar zones, features known as "shear belts" or "shear zones" are produced (Ramsay and Graham, 1970). As Ramsay and Graham (1970) pointed out, most geological studies have concentrated on establishing the state of strain over regions that are small enough to be considered as homogeneously strained. Diagrammatic methods have been employed to help visualize the variations in strain through the rock (e.g., Cloos, 1947; Dunnet, 1969; Elliott, 1965, 1968; Flinn, 1962; Ramsay, 1967; Ramsay and Wood, 1973). However, they have their limitations because for the computation of strain it is necessary to have objects in the rock whose original shape is known (e.g., Barr and Coward, 1974) and most rocks lack such objects.

Ramsay and Graham (1970) developed a method of describing the variation in strain across a shear zone. Their ideas were based on a concept they termed "strain compatibility". Basically, strains and displacements are interdependent, one on the other, so it follows that it is impossible for random and totally different strain states to lie adjacent to one another in a deformed body. Therefore, because rocks form a continuum of

connected particles, displacements in one part of the body will enforce displacements in an adjacent part. Thus there can be neither a random variation in the states of strain, nor a disordered arrangement of the body's internal fabric (Ramsay and Graham, 1970).

Penetrative planar fabrics such as schistosity are formed perpendicular to the direction of maximum finite shortening (e.g., Wilson, 1961; Ramsay, 1967; Oertel, 1970), representing the XY plane in the finite strain ellipsoid with axes $X \geq Y \geq Z$ (Ramsay and Graham, 1970). A penetrative mineral lineation can be produced parallel to the direction of maximum finite extension (Oertel, 1970; Schwerdtner, 1973b). Wilson (1961) noted that once rocks have become schistose, further deformation will probably take place along the planes of schistosity. Schwerdtner (1973b) showed how progressive deformation of most schistose rocks consists of an initial "anisotropy-creating phase", during which schistosity and mineral lineation develop, followed by an "anisotropic phase", during which numerous translational slip surfaces are generated parallel to the schistosity. This discontinuous deformation may be regarded as simple shear on a scale that is much larger than the average spacing of neighbouring slip surfaces (Schwerdtner, 1973a). But during a given period of progressive deformation, simple shear parallel to schistosity could lead to marked differences between the schistosity normal and the direction of greatest finite shortening (Schwerdtner, 1973b).

C. SHEAR STRAIN IN SHEAR ZONES

Ramsay and Graham (1970) showed that for a planar shear zone, the displacements across it could be interpreted as heterogeneous simple

shear without volume change, or some combination of heterogeneous simple shear with heterogeneous volume change. If the rock adjacent to the shear zone is undeformed, and there is no change in volume, the displacements within the zone can be attributed to simple shear only. In the shear direction the shear strain (γ) is given by:

$$\gamma = \tan \psi$$

where ψ is the angular shear (see fig. 16A). The initial orientation of the principal extension direction of the first formed strain ellipse is at 45° to the shear direction, and therefore also at 45° to the walls of the shear zone (Ramsay and Graham, 1970; fig. 17A). This angle (θ') decreases with increasing shear (fig. 17B). Ramsay and Graham (1970) suggested that a measure of the shear strain could be had using the expression:

$$\tan 2\theta' = 2/\gamma$$

Fig. 16A shows the distortion of a circle by simple shear. Fig. 16B is a plot of the variations of θ' for initial angles of 45°.

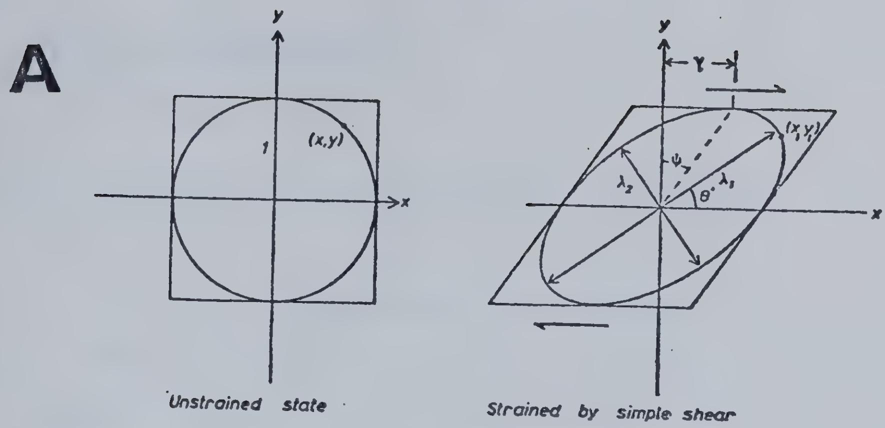
D. DISPLACEMENT ACROSS SHEAR ZONES

It is possible to integrate the shear strains from different points across a shear zone to compute the displacement across it. Following Ramsay and Graham (1970), the shear strain displacement δs over any small elemental sector of width δx is given by:

$$\delta s = \gamma \delta x$$

and the total displacement across the zone is the sum of all such elements:

$$s = \sum_{0}^{x} \delta s = \sum_{0}^{x} \gamma \delta x$$



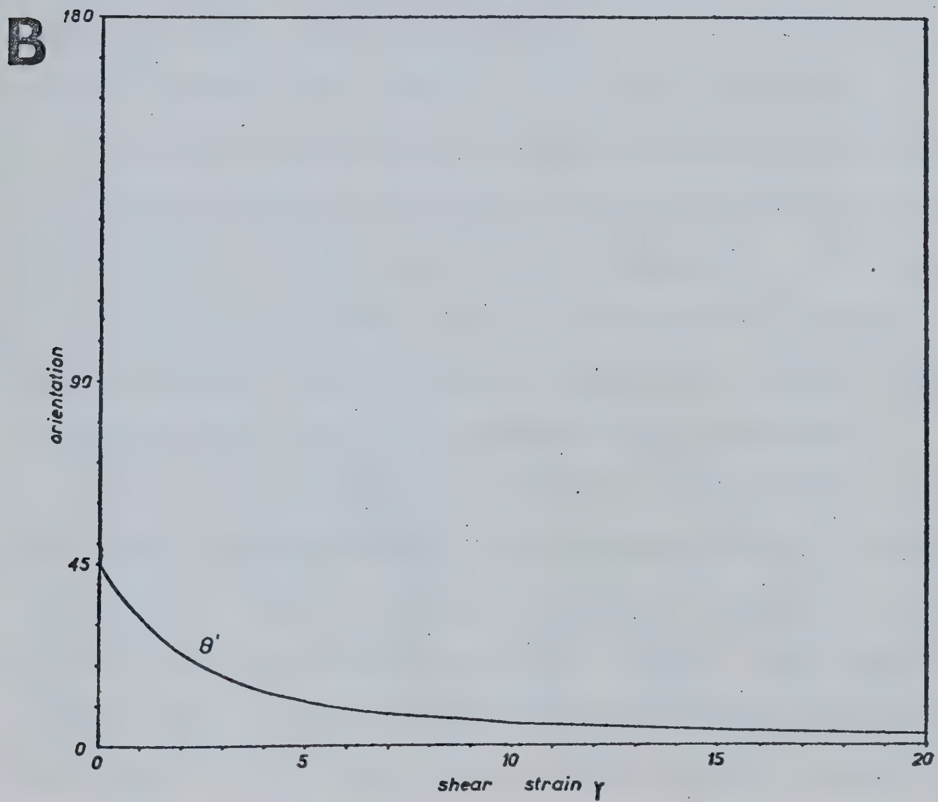


Fig. 16A. Distortion of a unit circle by simple shear in two dimensions; x,y and x_1,y_1: coordinates of a point before and after shearing; γ: shear strain = tan ψ; ψ: angular shear; λ_1,λ_2: principal quadratic extensions; θ': angle between the major axis and the shear plane (after Ramsay, 1967).

B. Variations of the angle θ' with increase in the shear strain γ. See text for explanation (modified after Ramsay and Graham, 1970).

which at the limit becomes:

$$s = \int_0^x \gamma dx$$

an integral which represents the area under the curve.

E. APPLICATION TO GIANT MINE

This study looked at that part of the mine near the trough of the synform, immediately north and south of section A-A' in fig. 15. Here the east-dipping ASD zone meets the west-dipping GB zone. The latter is cut by the "312" fault, but the ASD zone is continuous, and for the purposes of simple strain analysis it is assumed to be tabular.

Following the procedures of Ramsay and Graham (1970) outlined above, an attempt was made to determine the shear strain and displacement across the ASD zone. Several assumptions were necessary to allow computation of strain by their method. This was partly because the mine's workings do not penetrate totally unschistose country rock on either side of the shear zones and diamond drill information was not available.

First, the orientation of the ASD zone was assumed to be constant at N120°/65° (dip-direction/dip). The figures are derived from Brown, et al. (1959). Secondly, the zone's width, from unschistose rock to unschistose rock was assumed to be about 500 ft (150 m). From Ramsay and Graham (1970) it was assumed, thirdly, that the schistosity was originally at 45° relative to the shear zone (see section C above, and fig. 17A), and that this angle decreased during shear deformation. The fourth assumption was that there was little or no transformation or rotation of the schistosity (see, however, section F below). It was also assumed that there was no volume change (see below), and last, the analysis was based on the assumption that deformation took place by simple shear (Ramsay, 1967).

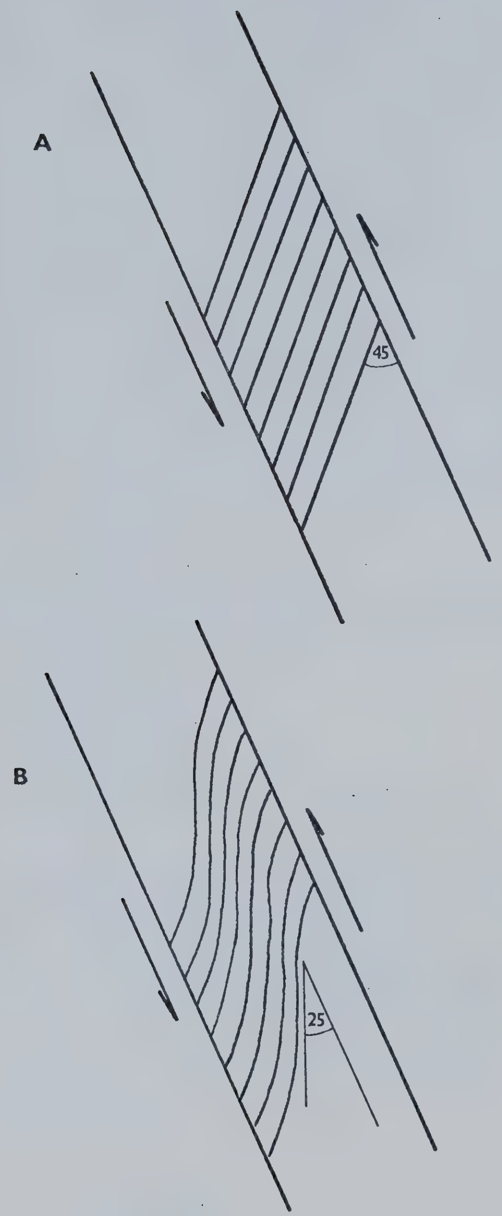


Fig. 17. A: Schistosity initiated at 45° to shear zone walls.
B: Angle between schistosity and shear zone walls decreases with progressive shearing deformation.

The orientation of the schistosity relative to the shear zone was then determined using the values from Table V (p. 61). Values from the West and Central divisions of Table V were compared with the attitude of the ASD zone, and the shear strain (γ) was determined by checking the relative orientation of the schistosity against the curve for θ' in fig. 16B. The value of γ obtained in this manner was plotted against distance across the shear zone reflected by the Mine Grid in fig. 18. A minimum figure of 2.5γ is derived for the shear strain across the ASD zone.

The area under the curve in fig. 18 gives the displacement (s) across the zone. From Ramsay and Graham (1970, see above):

$$s = \int_0^x \gamma dx$$

Substituting 500 for x and 2.5 for γ, this integral becomes:

$$\begin{aligned} s &= \int_0^{500} 2.5dx \\ &= 2.5(500-0) \\ &= 1250 \end{aligned}$$

Therefore, the thrust movement along the ASD shear zone was in the order of 1250 ft (or about 380 m).

Ramsay (1967) stated that after deformation the angle any lines make with the X direction is changed, so that:

$$\begin{aligned} \tan \theta' &= \frac{y_1}{x_1} \\ &= \frac{y(\lambda_2)^{1/2}}{x(\lambda_1)^{1/2}} \\ &= \tan\theta\left(\frac{\lambda_2}{\lambda_1}\right)^{1/2} \end{aligned}$$

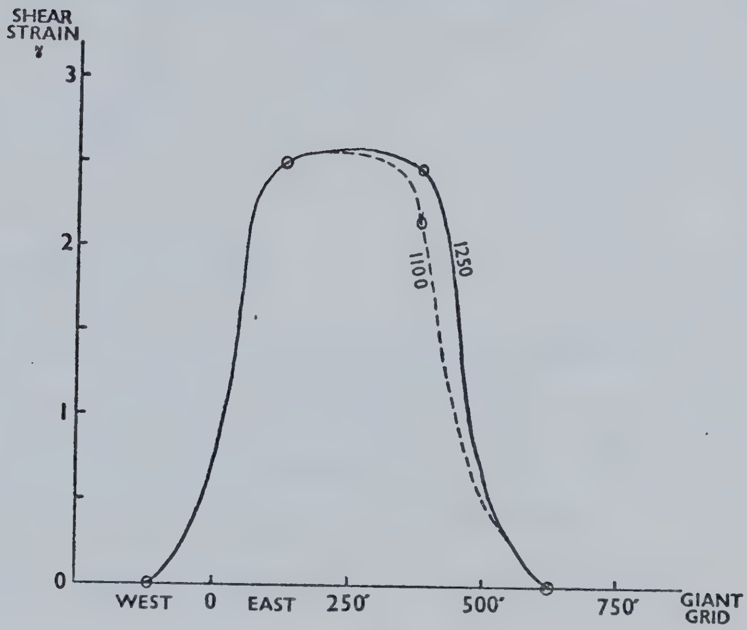


Fig. 18. Diagram showing the variation of shear strain γ across the ASD zone. 1250: 1250 Level; 1100: 1100 Level.

As schistosity is initiated at 45° to the shear zone wall (Ramsay and Graham, 1970), θ = 45° and therefore $\tan \theta = 1$, so:

$$\tan \theta' = \left(\frac{\lambda_2}{\lambda_1}\right)^{1/2}$$

Along the ASD zone $\theta' \simeq 20°$, therefore $\tan \theta' = \tan 20° = 0.364$. Substituting:

$$0.364 = \left(\frac{\lambda_2}{\lambda_1}\right)^{1/2}$$

or

$$\left(\frac{0.364}{1}\right)^2 = \frac{\lambda_2}{\lambda_1} = \frac{0.132}{1}$$

where λ_1 and λ_2 are the principal quadratic elongations of the strain ellipse (see fig. 16A). Note that this figure has been determined in two dimensions only: volume changes have not been considered. λ_1 is thus equivalent to X in the 3D strain ellipsoid (where $X \geq Y \geq Z$) and λ_2 is equivalent to Z. The X:Z strain ratio is therefore about 8:1.

F. DISCUSSION

As noted above, certain assumptions were made before the values for shear strain, displacement and strain could be determined. These assumptions were necessary in order to use Ramsay and Graham's (1970) method of shear strain calculation.

In detail the ASD zone may not be exactly tabular, as there are variations in the schistosity that reflect local variations in host rock and degree of strain, and it is difficult to define the exact edge of a gradational thing. However, the cross sections of Brown, et al. (1959) (fig. 15) show that in essence the ASD zone is a tabular structure. A figure

of 500 ft (150 m) was chosen as the best estimate of the distance between unschistose country rock on one side and unschistose country rock on the other. Up to 500 ft of schist are exposed on any one level. Taking into account that the zone is dipping, 500 ft from unschistose rock to unschistose rock is a rough but adequate estimate. A figure of 300 ft will give a displacement of 750 ft (230 m); a figure of 700 ft will give a displacement of 1750 ft (500 m).

Ramsay and Graham (1970) stated that the initial orientation of the principal extension direction of the first formed strain ellipse is at 45° to the shear direction and also to the walls of the shear zone (see fig. 17A). They reported that this angle decreases with increasing shear (fig. 17B). This seems quite reasonable, but it is debateable whether there was neither rotation subsequent to schist formation nor second stage, translational slip analogous to that proposed by Schwerdtner (1973b).

Microscope studies (Chapter VII) indicate there are indeed micro-faults roughly parallel to the schistosity and the banding. Pillows within the basalts, and pebbles in the basal conglomerate of the Jackson Lake Formation provide evidence of horizontal flattening. It is quite possible that there was a reorganization of the schistosity subsequent to shear zone formation, during which the schistosity was rotated to remain approximately normal to the direction of greatest finite shortening (figs. 19A and B). Prior to this flattening event the shear zone may well have had a gentler dip (cf. Escher and Watterson, 1974) and the internal schistosity may have described a far more acute angle to the shear zone walls than it does today. Examination of fig. 16B will show that this angle is

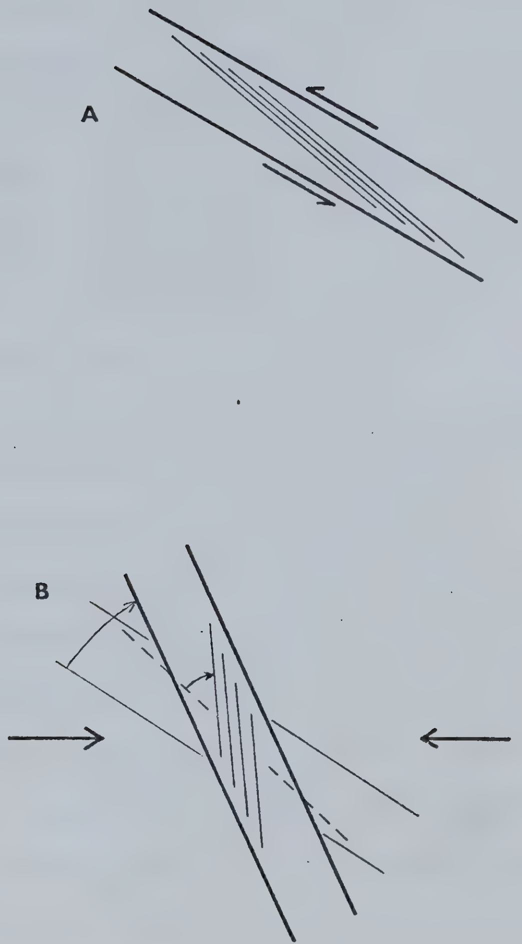


Fig. 19. A: Gently dipping shear zone with small angle between schistosity and shear zone walls.
B: Subsequent lateral compression causes rotation of shear zone. Nb. re-alignment of schistosity within the zone normal to direction of finite shortening.

critical in assessing the shear strain, especially where it is less than 20° to the walls of the shear zone (e.g., where the relative orientation of schistosity to walls is 20°, $\gamma = 2.5$; where it is 10°, $\gamma = 5.5$; and where it is 5°, $\gamma > 11.0$). Bearing this in mind, a shear strain of 2.5γ must be regarded as a minimum figure. Shear strains of 5.5γ and 3.7γ were obtained for the Con and Campbell shear zones using the method outlined above. The orientations, derived from Boyle (1961), were N278/53° and N278/63° for the Con shear zone and schistosity, and N273/47° and N276/63° for the Campbell shear zone and schistosity.

Volume change may or may not be significant. Barr and Coward (1974) reported a method for measuring volume change which involves combining measurements of the strain ratio with the angle between the surface of finite longitudinal strain and the principal extension direction in either the XY or XZ planes of the strain ellipsoid ($X \geq Y \geq Z$). On variolites in basic volcanics from the Antelope schist belt in Rhodesia, where $X:Z \approx 5:1$, they obtained two separate sets of measurements. One gave a volume gain of nearly 4%, the other a loss of 0.6%. Barr and Coward (1974) suggested the range represented a range of error rather than an actual range of volume change. However, in the Tati schists near Francistown, Botswana, a volume loss of more than 11% was obtained from chlorite spots in low-grade schists, where $X:Z \approx 6:1$. Unfortunately, the principal extension direction of the strain ellipsoid is not known at Giant so Barr and Coward's method could not be used. However, the rocks they looked at were Archean greenstones, apparently very like those at Yellowknife. One might therefore invoke similar volume changes for the Kam Formation.

Shear strains at higher tectonic levels are usually less than in basement rocks where $X:Z = 50:1$ is more commonplace (Escher and Watterson, 1974). Probably this is because more of the tectonic displacement at

higher levels is accommodated along thrusts and slides as opposed to penetrative ductile strain. Bak, et al. (1975) calculated shear strain values of 6.0γ and above for the Nordre Stromfjord and Ikertôq shear belts of West Greenland, which are very much wider than the gold-bearing shear zones at Yellowknife (the Ikertôq shear belt is 40 km across), and which have strike-slip movements along them of up to 200 km (Bak, et al., 1975). Coward, et al. (1973) proposed similar transcurrent displacements to account for regional deformation in the Limpopo belt. Glikson (1970) obtained strain ratios of 3:1 for the Kurrawang beds in the Kalgoorlie greenstone belt, Western Australia.

Escher and Watterson (1974) proposed a model of simple shear for gently dipping thrust belts wherein the X (stretching) axis of the strain ellipsoid is transverse to the boundary of the belt. They noted that a "feature of the strain ellipsoid in simple shear is that the stretching axis is a preferred direction for the initial fold axis of fold initiated by buckling, because all planes which contain the X-axis also contain a shortened element; a plane initially parallel to the XZ-plane for example will develop buckle folds with axes parallel to the stretching direction" (Escher and Watterson, 1974, p. 229). As an example they cited supracrustal rocks which are being deformed for the first time. According to Escher and Watterson's simple shear model the folds formed first will have axes which are parallel to the Y-axis and with homogeneous deformation there should be no reorientation of the axes unless there was a change in shear direction. The so-called "drag folds" reported by Brown, et al. (1959) were not seen in the study area, and Brown, et al., did not report the orientation of fold axes. One could speculate that such "drag folds" are in fact equivalent to Escher and Watterson's buckle folds. First formed schistosity (parallel to XY plane) should be axial planar to such folds.

G. FAULTS, JOINTS AND FIBROUS LINEATIONS

Price (1966) stated that a fault is a shear plane of fracture which exhibits signs of differential movement of the rock mass on either side of the plane. Joints are cracks and fractures along which there has been extremely little or no movement (Price, 1966). Both faults and joints are non-penetrative structures. They commonly display lineations - either grooved striae or fibrous mineral growths - that are due to slip along the structures. Langenberg (1975) reported that the movement direction of the last deformation can be reconstructed using these lineations. Such "slip-linears" are the traces of the movement direction and thus they are the orthographic projection of this direction on the plane of shear (Langenberg, 1975). If it can be shown that the traces of sliplinears on a group of random planes do in fact represent the orthographic projections of a single line on those planes, then the regional kinematic direction can be determined (Cruden, 1971).

Consider the sliplinear traces and the shear plane containing them: Cruden (1971) termed the normals to the sliplinear traces on the shear plane "trace normals". He showed that if the trace normals lie on a great circle of a stereographic net, the traces are traces of a single lineation. The pole to this common great circle is the direction of the lineation (Cruden, 1971).

A nearly conjugate set of faults cuts across the study area at Giant (see Chapter VI and fig. 3B). In fig. 20A the planes of these faults have been superimposed on the stereogram of all lineations (fig. 13A). Six lineation trace directions are evident, four of which plot on the faults striking north-south, and two of which fall close to the northeast

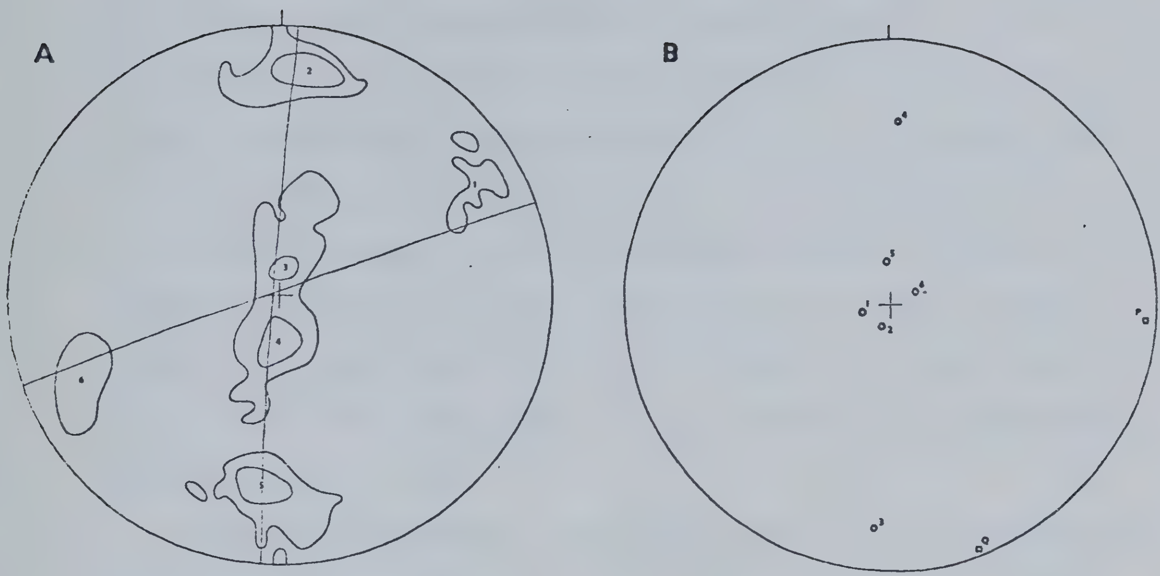


Fig. 20. A: Density diagram with lineations (2,5% contour interval - 212 observations) and traces of the two major fault directions. 1 through 6: the six major lineations.
B: Circles: trace normals; see text for explanation of P, Q.

striking faults. Following Cruden's procedure, the trace normals were then plotted, as shown in fig. 18B. They lie on a great circle that represents an almost vertical north-striking plane, the pole to which is point P. P should therefore be the regional kinematic direction (Cruden, 1971). Because 87% of all the lineations observed are fibrous mineral growths (mainly carbonate minerals), so P must indicate a nearly horizontal east-west extension direction. (It is also possible to derive in the same manner a northwest-southeast extension direction by assuming lineations 2 and 3 (fig. 20A) lie on the northeast-striking faults. Trace normals would then lie on a great circle giving a pole at Q. However, this interpretation is not favoured owing to the lineation pattern of fig. 13A.).

The conjugate pattern of faults suggests that they were formed during compression, and their rough symmetry about the shear zone schistosity indicates this occurred at about the same time the schists were formed. It is conceivable that ductile deformation gave way to brittle fracturing late in the shear zone's history. Relaxation of compressional stresses allowed such extensional structural features as mineral growth along the earlier formed fault surfaces. The Western Granodiorite lies immediately west of Yellowknife. Its cooling and contraction would cause the east-west extension described above.

Chapter IX

SUMMARY AND CONCLUSIONS

Gold has been mined at the Giant Yellowknife Mine for nearly thirty years. Over six million tons of gold ore have been extracted from a series of schistose shear zones, yet a working model of the Giant structure has not been published. This study has attempted to explain the structural geology of part of the Giant Mine, and briefly relates it to the general structure of the Yellowknife area.

The shear zones are the result of ductile deformation that affected the Archean Yellowknife greenstone belt. A gneissic basement has been partially remobilized and granitic plutons have intruded the supracrustal rocks (McGlynn and Henderson, 1970). Greenstone belt formation, volcanism and sedimentation, anatexis and deformation of the supracrustal sequences have all taken place along great, linear mobile zones that were tectonically active until about 2500 m y ago (e.g., Sutton, 1975). In the Yellowknife area, a syncline plunges south along Yellowknife Bay, and whereas its east limb comprises complexly folded sedimentary and volcaniclastic units, its west limb consists of a vertically dipping pile of mainly basic and intermediate extrusives (Jolliffe, 1942). These volcanic rocks have suffered deformation along shear zones. The base of the greenstones is not seen, it having been intruded by the Western Granodiorite, and the contact subsequently faulted by the West Bay fault (Brown, 1955). Regional greenschist to epidote-amphibolite facies metamorphism is related to granitic emplacement (Boyle, 1961).

Gold ore occurs in a system of schistose shear zones which strike about N30°, subparallel to the stratigraphy. They dip more gently than

the steeply dipping volcanic flows, which on the Giant property are overturned and dip west at 65 to 85° (Henderson and Brown, 1966). Dilatant zones within the schists have allowed silicification and deposition of the sulphide ore minerals (Coleman, 1957; Boyle, 1961). The gold may have been transported as an oxidized chloride complex and dumped at moderate temperatures in the greenschist facies (Fyfe and Henley, 1973). The shear zones can be divided into those that are concordant and those that are discordant. The former tend to be narrow and discontinuous, but the latter locally attain hundreds of meters in width and contain the larger gold ore bodies (Boyle, 1961; Henderson and Brown, 1966). The Giant system is discordant, and crops out beneath the Baker Creek valley.

Structural data were collected from four levels of the mine near its 'C' Shaft in a series of 100 ft long straight line traverses. The observations were recorded on specially designed, computer-oriented field sheets. Information general to each traverse was noted on "traverse line sheets". Non-penetrative structures were described on "discontinuity data sheets". Observations on rock types and penetrative structures were recorded on "lithology data sheets". The rules for recording data are given in the DISCODAT manual in the Appendix.

The initial step in the creation of a data file was to punch the data from each field sheet onto computer cards. The information was subsequently transferred to tape. Files of line numbers, called "keys", referenced subsets of data (Ramsden, 1975). Mathematical manipulation of the data was based on the use of direction cosines of unit vectors. Built into the computer programs were corrections for bias caused by non-random orientation of the traverse lines (Terzaghi, 1965). A ser-

ies of equal area density diagrams was generated using the computer. These included diagrams for poles to joints, veins and faults, and diagrams for the various lineations observed, notably fibres and grooves. Each such structural type was investigated by level and longitude, and by combinations of both. In total, the computer printed more than 200 stereograms, with and without correction factors.

Throughout the study area there is a nearly vertical joint set with a dip-direction of about N305° that reflects the penetrative mineral schistosity of the shear zone. The central parts are characterized by a steeply southwest-dipping joint set, but lack another set, common elsewhere, that has a moderate to steep dip and a dip-direction just south of east. An approximately horizontal joint set is found locally everywhere in the study area. An approximately conjugate set of nearly vertical faults cuts the area. One group has a dip-direction of N320-345°; the other dips westwards. This conjugate set is bisected by the shear zone schistosity. Three sets of veins predominate: one has an orientation of about N240/75, another dips steeply eastwards (about N90/85), and the third dips steeply to the south (N185/85).

Of the observations on lineations on fault and joint surfaces, nearly 90% were fibrous mineral growths (mainly carbonate) and the remainder mostly grooved slickensides. All stereograms show a north-south girdle of points about a horizontal east-west axis. The trends and plunges of the four most prominent clusters of points are: N10-10°; N20-75°; N180-70°; N185-20°. Less common lineations plunge gently northeast and southwest. These lineations are "slip linears", and they represent the orthographic projections of a single line on the planes

on which they occur (Langenberg, 1975). Their trace normals lie on a great circle of a stereographic net, the pole to which is the direction of tectonic shortening or extension (Cruden, 1971). In this case, it can be shown there was an east-west extension direction, and extension is assumed to have occurred subsequent to the formation of the conjugate joint set.

Thin sections were cut for the investigation of micro-structures and veins. Schistosity is locally enhanced by both (?) metamorphic banding and concordant vein development. Microfaults are a common feature subparallel to the schistosity, and from place to place there are small folds. Thin shear zones locally cross the schistosity. Secondary discordant quartz-carbonate and carbonate veining is widespread. Staining revealed that ankerite becomes an increasingly important groundmass mineral towards the centre of the shear zones. Iron-free calcite is abundant in the groundmass and is the most important vein carbonate. Dolomite is a rare vein mineral.

Strain analysis across the ASD zone was based on the fact that the schistosity in a shear zone is initiated at 45° to the shear direction, but that with progressive shear this angle decreases (Ramsay and Graham, 1970). The orientation of the schistosity from various points across a shear zone will give a measure of the shear strain across the zone. It is possible to derive figures for the strain ratio and the relative displacement across the zone as well. Using this method it was concluded that the minimum shear strain across the ASD zone is 2.5γ, that there was approximately 380 m relative thrust movement along the shear zone, and that the strain ratio is $X:Z = 8:1$(($X \geq Y \geq Z$ in the strain ellipsoid).

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APPENDIX

PREAMBLE

DISCODAT is a computer based system to aid the collection, retrieval and manipulation of data on discontinuities in rock masses. It aims to relieve the geologist of much of the tedious clerical work involved in transforming his observations into a model for the rock mechanics engineer but makes no attempt to supplant his judgment.

The components of the system are three types of form for recording field observations, and computer software for retrieving, manipulating and displaying the data. This manual only describes the use of the forms. Though it offers some reasons for some of the rules it lays down, full appreciation of the logic of DISCODAT requires study of the software. While the system has considerable flexibility, restrictions on the use of the coding forms should not be violated without considering the problems this may cause in the software.

The description of the coding forms that follows is aimed at those with an elementary knowledge of geology; a text, such as "A Manual of Field Geology" (Compton, R.R., 1962, John Wiley, New York), would supplement it.

A. INTRODUCTION

DISCODAT assumes that the geologist has explored by traversing or line mapping, walking on a bearing, recording what lies in his path. It then provides a correction (by Terzaghi's method) of the bias in his observations and a record of the position of each observation relative to the start of the traverse. DISCODAT is thus suited both to detailed mapping of adits and along benches in mines and to reconnaissance surveys. It can be adapted to the logging of drill core.

DISCODAT can be used for other survey systems but will lack the corrections described above.

Data for DISCODAT is recorded on three types of form.

1. The Traverse Line Sheet

The traverse line sheet records information which is common to the whole traverse line. The grid coordinates of the start of the traverse line and its elevation, the direction of the traverse line, the structural domain and the rock formation the traverse crosses, the reference direction of the observations, and the geologist's personal location code can be entered.

2. The Discontinuity Data Sheet

The discontinuity data sheet records discontinuities observed along the traverse line by type, orientation, filling, folding, and size and water content. Orientation and type of any linear structures on the discontinuities, the rock type and the distance to observations can also be recorded.

3. The Lithology Data Sheet

The lithology data sheet records information on rock lithology, hardness, grain size, and the characteristics of any penetrative surfaces in the rock, its type, orientation, spacing, folding, and lineation.

RECORDING RULES

The following rules for recording aim at making the completed forms as legible and unambiguous as possible.

1. All letters should be capitals.
2. All numbers should be right-hand justified.
3. No decimal points should be inserted.

4. The letter "O" should be written Ø to distinguish it from the number zero.
5. One is indicated by a vertical line and distinguished from the letter "I" by the horizontal bars on the top and bottom of the "I".
6. Care is necessary to keep the letter "Q" distinct from the letter "O".
7. The letter Z should be written Ƶ to distinguish it from the number 2.

A detailed guide to the completion of each of the forms follows.

MNEMONICS

Tests show that data recording is slowed and errors occur if much numerical coding of non-quantitative information is used. These errors could have serious consequences for the whole analysis. Using mnemonically coded abbreviations reduces the likelihood of recorder error and simplifies checking the forms.

Mnemonics can initially be generated by the following rules (Franklin System):

1. Preserve the first letter of all words.
2. Delete in order a, e, i, o, u, w, h, y.
3. Delete one of each double.
4. Delete in order, t, n, s, r, l, and d.
5. Truncate from right to the required number of letters.

SIZE

An extended, modified Wentworth scale can be used to indicate size.

Description	Size Limits	Code
	> 60 m	N
	20 - 60 m	M
	6 - 20 m	L
	2 - 6 m	K
	0.6 - 2 m	J
Boulders	0.2 - 0.6 m	I
Cobbles	60 mm - 0.2 m	H
Coarse Gravel	20 - 60 mm	G
Medium Gravel	6 - 20 mm	F
Fine Gravel	2 - 6 mm	E
Coarse Sand	0.6 - 2 mm	D
Medium Sand	0.2 - 0.6 mm	C
Fine Sand	0.06 - 0.2 mm	B
Silt, Clay	< 0.06 mm	A

This size scale is employed to describe grain size, spacing and the size of discontinuities. An average pace is about a metre in length. Fine sand grains are just distinguishable by the naked eye.

B. IDENTIFICATION

The code identifying the traverse line sheet is also placed for reference on the other two sheets. It plays no part in calculations but may be used for sorting data.

The code is formed by placing the year in the first column (1971 = 1, 1972 = 2) the observer's initials are in the next two columns and the station from his records is in the final columns (maximum station number is 9999).

UTM COORDINATES

The Universal Transverse Mercator (UTM) grid is a world-wide system of 60 zones, each six degrees of longitude wide and extending from the equator to the 80th parallel of latitude, north and south (in Canada, the grid is extended to 84°N).

In Canada, the UTM grid is shown on the NTS standard series of maps at scales of 1:250,000, 1:50,000, and 1:25,000 and on some maps at scales of 1 inch to 1 mile, 1 inch to 4 miles and 1 inch to 8 miles.

Northing and easting grid lines form the squares, and intersect in grid coordinates. The grid coordinates of a point have three parts:

1. The UTM zone number in which the point is located.
2. The easting, the number of metres from the left boundary of the zone to the point.
3. The northing, the number of metres from the equator to the point.

In the UTM system, the location of a point anywhere in the world can be expressed to the nearest metre as a 15 digit number. Record the coordinates of the start of the traverse. The first 2 digits are the zone number; the next 6 digits represent the easting and the last 7 digits represent the northing.

ELEVATION

The elevation of the start of the traverse line in feet above sea level. Elevations below sea level are indicated by a negative sign in the first column.

LOCAL GRID

Space is provided for any local numerical rectangular grid coordinates. Numbers should be positive, decimal points omitted. The easting is the first six columns and the northing in the next six columns.

TRAVERSE DIRECTION

Plunge is the inclination of the line of traverse to the horizontal. No record indicates a horizontal traverse line, uphill traverses are indicated by a negative sign in the first column.

Trend of the traverse line is measured in degrees clockwise from true north. Trends directed to true north should be recorded as 360. No record indicates no observation was made hence Terzaghi's correction cannot be calculated.

In a magnetically disturbed area the required value of the trend cannot be entered immediately. The minimum information necessary is an accurate location of the start of the traverse, a bearing onto some distant object whose position is known and the bearing of the traverse. These two bearings can be made with a Brunton compass and entered under remarks on this sheet.

PIT BENCH

1. Level

Bench level is recorded in these four columns by the system operated at the mine. Popular systems include numbering consecutively from the top of the pit downwards or recording the height from bench to surface.

2. Location

A three letter code for the location of the bench face being mapped.

DOMAIN

A preliminary analysis of the geology of the area should allow its division into areas in which the fabric of the rock mass is statistically homogeneous. These areas are termed domains. They may be lettered using the local grid, AA is the domain at the origin, AB is the next northerly domain. BA is the next unlettered easterly domain.

FORMATION

The geological formation or unit to which the lithology belongs is recorded to a 3 letter mnemonic formed by the rules of Appendix 1.

REFERENCE DIRECTION

If a Brunton or Freiberg compass is used to measure the orientation of surfaces in the survey, the origin of the horizontal circle should coincide wtih the mark or pin on the casing. The compass should not be adjusted to read true north.

Enter the magnetic declination on a 360 degree scale (for example, if magnetic north is locally 15 degrees west of true north, enter 345). If a Brunton compass is being used enter the magnetic declination plus 90 degrees; if this figure is greater than 360 degrees subtract 360 degrees and enter the result. For true north, use 360 (not 000). If measurements have been made using a clinorule, enter here the trend of the traverse minus ninety degrees. If this is less than or equal to zero degrees, add 360 degrees and enter the result.

REMARKS

Other information - date of mapping, duration of exposure of rock face, more detailed descriptions of rocks, reliability of exposure, etc.

C. DISCONTINUITY

Discontinuities recorded under this classification should be non-penetrative on the mesoscopic scale (the scale that ranges from large hand specimens to outcrops). Information about penetrative discontinuities should be recorded on the lithology survey sheet.

Typically, unconformities and faults are non-penetrative structures whereas bedding and cleavage are penetrative structures. However, when units are extremely thickly bedded the bedding may be treated as a non-penetrative structure. Similarly bedding planes showing evidence of slip should be treated as non-penetrative faults or shears.

When jointing is very closely spaced and regular, as, for example, the cleat in some coals, it may be treated as a penetrative structure.

SURFACE NUMBER

Observations on discontinuities are numbered in sequence from one along the exploration line described on the traverse line sheet. Up to 99 observations can be accommodated before a new traverse must be started.

DISTANCE

Record the distance along the line of traverse from the start. Units are tenths of a foot (decimal points omitted) and measurement is to where the projected discontinuity surface would cut the tape stretched along the face. Most common length of a traverse is 100 feet.

TYPE

The type of discontinuity is recorded as a three letter mnemonic formed by the rules specified in Appendix 1. Mnemonics follow the definition of each discontinuity type. These structures are illustrated in Figure 3.

1. Axial Surface (AXS)

Surface joining the fold axes on successive folded surfaces.

2. Bedding (BDG)

Regular layering in sedimentary rocks marking lithological contacts.

3. Cleavage (CVG)

Closely spaced parallel surfaces of fissility in unmetamorphosed rock not parallel to lithologic contacts.

4. Contact (CNT)

Surface between two rock types, one or both of which is not sedimentary.

5. Fault (FLT)

Surface of shear recognizable by the displacement of another surface that crosses it. Faults can be classified by the direction of slip of the fault block which rests on the fault plane (the hanging wall block). Refer to slip and separation under type of lineation.

6. Gneissosity (GNS)

Surface parallel to lithological layering in metamorphic rocks. This term should also be used to describe suspected flow banding in igneous rocks.

7. Joint (JNT)

Fracture in rock mass along which there has been no identifiable displacement.

8. Schistosity (SCS)

Surface of easy splitting in a metamorphic rock. It is defined by the preferred orientation of metamorphic minerals.

9. Shear (SHR)

Surface of shear without identifiable displacement. It can be recognized by slickensides, polishing or slickness of the surface or striations on the surface.

10. Unconformity (UCF)

Eroded surface covered by sedimentary rock.

11. Vein (VIN)

Fracture in rock with a filling apparently injected at the time the fracture formed.

ORIENTATION

1. Strike

The direction of a horizontal line on the discontinuity. Looking up the direction of dip, measure the orientation of the right hand end of the strike line. This is usually done with a Brunton compass. The compass should not be adjusted to read true north. If a Freiberg compass is used, record the dip direction of the discontinuity under strike; again, the compass should not be adjusted.

The regional magnetic field is, however, locally distorted by some ore bodies and by metal pipes and tracks within five paces of the outcrop. In this case, traverse directions should be arranged so that the rock face lies to the observer's left when facing down the traverse. Then, facing down the traverse, measure in a clockwise sense the angle between the trend of the traverse (zero degrees) and the strike line

using a clinorule. Place one end of the rule horizontally on the discontinuity and open the other to parallelism with the traverse tape.

Refer to the discussion under Reference Direction.

2. Dip

The maximum acute angle the discontinuity makes with the horizontal can be measured with a clinometer or clinorule.

If a clinorule has been used to measure the strike, record the dip as negative if the dip direction is anticlockwise from the measured strike direction.

SIZE

The maximum lengths of the discontinuity visible parallel to the strike of the discontinuity and parallel to the dip of the discontinuity are recorded in separate columns. The lengths are classified according to Size under Section A.

If only one termination of the discontinuity is visible in the strike direction record 1 under Strike Ends. If no terminations are visible, record 2. Terminations in the dip direction can be similarly recorded under Dip Ends.

INFILLING

Infilling includes any material that occurs patchily on the discontinuity. Material that is continuous over a discontinuity should be mapped as a separate lithology. Infilling is thus taken to include materials derived from breakage of the country rock due to fault movement, material weathered in-situ and infilling materials deposited between the structural planes (calcite, quartz, and evaporites).

1. Type

The type of infilling material is recorded using single letter mnemonics. We can easily distinguish:

a) Breccia (B); coarse angular fragments or rock from the walls of the discontinuity.

b) Calcite (C); soft, white and soluble.

c) Evaporites (E); gypsum, halite, anhydrite, etc.

d) Feldspar (F); hard, easily weathered, good cleavages, insoluble.

e) Mud (M); disaggregated rock (soil) in which individual grains are not visible.

f) Ore (O); valuable.

g) Quartz (Q); hard, resistant to weathering, white.

h) Sand (S); disaggregated rock (soil) in which individual grains are visible.

i) Coal (Z).

The more abundant material should be listed in the first of the two columns.

WATER

We can distinguish:

Code

1 The discontinuity is tight; water flow along it is not possible.

2 The discontinuity is dry with no evidence of water flow.

3 The discontinuity is dry with evidence of water flow, rust staining of discontinuity surface, etc.

4 The discontinuity is damp but no free water is present.

5 The discontinuity shows seepage, occasional drops of water, no continuous flow.

Code

6 The discontinuity shows a continuous flow of water.

ROUGHNESS

We can distinguish different second-order asperity size ranges on discontinuities.

Category

1	Polished surface
2	Smooth
3	Defined ridges
4	Small steps
5	Very rough

WAVINESS

Waviness is measured by placing a clinorule on the discontinuity surface in a direction normal to the crest (or axis) of the waves. Then open the rule until the opening arm touches the surface. Move the position of the hinge on the surface until the angle between the arms of the rule is at a minimum. Record the angle in degrees between the arms (which should be open to the full foot length when making this measurement). Planes will be recorded as 180, no record indicates irregular or inaccessible waviness.

The pitch of the axis should be recorded under line pitch and fold axis should be recorded under line type.

LINE TYPE

The type of linear structure is recorded as a 3 letter mnemonic formed by the rules of Appendix 1. The mnemonics follow each definition. No record in this space indicates no observation was made.

We can distinguish the following types of line (Fig. 5).

1. Striae on slickensides fall into two types: a linear fibre elongation caused by parallel growth of elongate crystals in the slickensides, here called fibrous (FBR), and grooves cut by asperities to the fault surface (GRV).

2. A fold axis is the generatrix of the fold -- the line which moved parallel to itself would generate the folded surface (FDX).

3. The slip on a fault is the direction the hanging wall block has moved with respect to the footwall block. The slip direction can be measured when a point on the hanging wall can be identified with a point on the footwall or when striae can be seen (SLP).

4. Separation. A uniformly dipping bed of rock intersects a fault plane in a line and observations of the displacement of the bed by the fault can only estimate slip perpendicular to the line of intersection; the component of slip along the line of intersection remains unknown. Most geological observations are of apparent slips or separations (SPR).

LINE PITCH

Measure the clockwise angle on the plane from the right-hand end of the strike line of the plane to the line which is to be recorded. Use the 360 degree scale -- an upward slip direction making an angle of 45 degrees with the right-hand end of the strike line would be recorded as 315. Record the downward pointing ends of axes.

The measurement is simply made with a clinorule by placing one arm horizontally on the surface and opening the other to parallelism with the line.

ROCK TYPE

Letter the different rock types encountered along the traverse (and described on the lithology sheet) in sequence from A. Record here the lithology up traverse from the discontinuity described.

IDENTIFICATION

See Section B - Identification.

D. NUMBER

Recorded lithologies are numbered in sequence from one along the traverse line.

1. Rock Type. See Section C - Rock Type.

2. Lithology.

The lithology up traverse from the discontinuity being described is recorded using a three letter mnemonic. Rock exposed down traverse is recorded with the next surface observation.

A preliminary list with mnemonics can be conveniently divided into:

IGNEOUS ROCK

Plutonic		Volcanic	
Anorthosite	NRS	Andesite	ADS
Diorite	DRT	Basalt	BSL
Gabbro	GBR	Dacite	DCT
Granite	GRN	Latite	LTT
Granodiorite	GDR	Pegmatite	PGM
Monzonite	MZN	Rhyolite	RLT
Peridotite	PRD	Trachyte	TRC
Syenite	SNT		

A field guide to the use of these names is given in the following table.

NOMENCLATURE OF IGNEOUS ROCKS

Plagioclase Content as % of Total Feldspar	Quartz < 10%	Quartz > 10%
Less than 1/3	SYENITE Trachyte	GRANITE Rhyolite
1/3 to 2/3	MONZONITE Latite	QUARTZ MONZONITE
More than 2/3	DIORITE GABBRO (pyroxene present) ANORTHOSITE (plagioclase only) Andesite Basalt (pyroxene and olivine present)	GRANODIORITE Dacite QUARTZ DIORITE (rich in hornblende and pyroxene
Less than 10% Feldspar	PERIDOTITE (more than 5% olivine)	
Special Types	PEGMATITE - silicic, dyke rock having conspicuously coarser texture than parent	
	NOTE: UPPER CASE = Coarse Grained Rocks Lower Case = Fine Grained Rocks	

METAMORPHIC ROCKS

Regional Metamorphism

Amphibolite (AMP)	-	medium to coarse grained, dominantly amphibole and plagioclase, commonly massive but possibly foliated and layered.
Granulite (GRL)	-	fine grained, pyroxene, garnet and quartz in flattened lenticles oriented parallel to the foliation, hornblende or mica minor.
Gneiss (GSS)	-	dominantly quartz and feldspar, roughly or poorly foliated, foliation may be accompanied by compositional layering.
Phyllite (PHL)	-	fine grained, abundant chlorite and mica define foliation surfaces. Grain size intermediate between slate and schist.
Slate (SLT)	-	very fine grained rock possessing very good cleavage.
Schist (SCS)	-	rich in lamellar or platy minerals (micas) in sub-parallel orientation, quartz or feldspar may occur.
Quartzite (QRZ)	-	dominantly quartz, uniform grain size.

Contact Metamorphism

Hornfels (HFL)	-	fine to medium grained, without preferred orientation, cleavage is absent, large crystals of garnet, andalusite or staurolite may be present.
Marble (MBL)	-	mainly calcite or dolomite, foliation weak.
Skarn (SKR)	-	hornfels with pyroxene, garnet and carbonate.

Cataclastic

Mylonite (MLN)	-	fine grained, foliated rock which has been completely pulverized by extreme differential movement.
Augen Gneiss (AGS)	-	gneiss with lensoid grains in finer grained groundmass.

SEDIMENTARY ROCKS

Detrital

Arkose (ARK)	- quartz and more than 25% feldspar.
Conglomerate (CGM)	- consolidated (rounded) clastic particles larger than 2 mm.
Greywacke (GRK)	- quartz, feldspar, rock chips, pelitic matrix, angular grains, tough, greenish grey colour.
Mudstone (MDS)	- consolidated mud, clay minerals.
Sandstone (SDS)	- dominantly quartz, feldspar less than 25%.
Shale (SHL)	- clay minerals, finely fissile.
Siltstone (SLN)	- indurated silt.

Biogenic

Chert (CHR)	- silica, grain size less than 1/256 mm, bedded, nodular or massive.
Coal (COL)	- carbon.
Dolomite (DLM)	- chiefly dolomite, massive.
Evaporite (EVP)	- halite, anhydrite, gypsum.
Limestone (LMS)	- chiefly calcite, massive.
Ironstone (INS)	- mixture of iron, clay, silica, and carbonate.

Pyroclastic

Agglomerate (AGM)	- consolidated angular clastic particles larger than 2 mm.
Tuff (TEF)	- consolidated ash.

3. Hardness.

A set of simple mechanical tests can be used to classify the hardness of a rock. The classification gives a first estimate of the unconfined compressive strength of the material.

a) S1 (Very Soft) - Easily mouled by hand, shows distinct heel marks.

b) S2 (Soft) - Moulded by strong hand pressure, shows faint heel marks.

c) S3 (Firm) - Moulded with difficulty, difficult to cut with hand spade.

d) S4 (Stiff) - Cannot be moulded by hand, cannot be cut with a hand spade and requires hand-picking for excavation.

e) S5 (Very Stiff) - Difficult to move with handpick, requires pneumatic shovel for excavation.

f) R1 (Very Soft Rock) - Crumbles under firm blows with point of geological pick, can be peeled by a pocket knife.

g) R2 (Soft Rock) - Can be peeled by a pocket knife with difficulty, shallow indentation made by firm blow of geological pick.

h) R3 (Average Rock) - Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of hammer end of geological pick.

i) R4 (Hard Rock) - Specimen requires more than one blow with hammer end of geological pick to fracture it.

j) R5 (Very Hard Rock) - Specimen requires many blows with hammer end of geological pick to fracture it.

4. Grain Size.

Record in successive columns the size of the finest and coarsest 10% of grains in the rock. Use the scale in Section A - Size.

SURFACES

Most penetrative surfaces will be tight to water. Those that are not should be recorded on the discontinuity data sheet. Similarly surfaces showing any infilling belong on the discontinuity data sheet.

This classification is intended to reduce the labour in recording closely spaced surfaces which are uniformly oriented over large areas. The size of the surfaces will always fall in the size classification 9.

1. Type

Clearly not all individual examples of a penetrative surface need be measured. The surface should be sampled whenever there seems to be a change in its orientation and then at least five measurements of separate planes should be made.

Classification is as in Section C - Type.

2. Orientation

Bedding planes have a facing direction, and overturned bedding can be recorded as having dips greater than 90 degrees.

See Section C - Orientation.

3. Spacing

The average spacing between penetrative discontinuities can be classified using the familiar grain size scale (see Section A - Size).

4. Waviness

See Section C - Waviness.

LINE

1. Type. See Section C - Line Type.

2. Pitch. See Section C - Line Pitch.

IDENTIFICATION

See Section B - Identification.